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A comparison of bobcat (Lynx rufus) habitat suitability models derived from radio telemetry and incidental observations

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A COMPARISON OF BOBCAT (*LYNX RUFUS*) HABITAT SUITABILITY MODELS DERIVED FROM RADIO TELEMETRY AND INCIDENTAL OBSERVATIONS

BY

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DEDICATION

I dedicate this thesis to the memory of Deborah S. Stalter. 'Aunt' Debbie was my first science teacher and a close member of my family. She played an important role in my personal life but also to my professional career as she introduced me to the scientific method and ecology. Whether studying in the Amazon rainforest or completing my thesis at UNH, I am constantly reminded of the lessons she taught me many years ago.

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ABSTRACT

A COMPARISON OF BOBCAT (*LYNX RUFUS*) HABITAT SUITABILITY MODELS DERIVED FROM RADIO TELEMETRY AND INCIDENTAL OBSERVATIONS
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Habitat suitability models derived from data obtained from radio telemetry and citizen observations were developed to evaluate habitat selection of monitored bobcats, compare statewide habitat suitability models and maps developed using locations from telemetry and citizen observations, and produce statewide population estimates. In the winter of 2009-2010, adult bobcats were captured in southwest New Hampshire and equipped with GPS tracking collars. GPS locations were used to calculate home ranges and to build habitat suitability models using resource selection functions (RSF) following a used vs. available design. RSFs were also applied to recent reported statewide sightings. Comparisons between these two approaches did not support the use of solicited sightings to manage a statewide bobcat population. Statewide abundance estimates were made using a telemetry model and habitat-area requirements.

CHAPTER I

INTRODUCTION

It is essential for wildlife biologists to identify animal-habitat associations for the conservation and management of a species (Boyce and McDonald 1999, Manly et al. 2002). As a result, a variety of approaches have emerged that are used to identify biotic and abiotic features that affect the distribution and abundance of a particular species. Among the factors a researcher must consider when selecting an approach to investigate how animals respond to habitat heterogeneity is the spatial scale at which the information is gathered and subsequently applied.

Sampling techniques used to identify animal-habitat associations and habitat selection that are limited to small focal areas include direct sampling techniques. Direct and intensive sampling often includes captures and radio telemetry (Litvaitis et al. 1992) and have typically been the chosen option in the study of carnivore ecology (Gompper et al. 2006). Global positioning system (GPS) telemetry provides researchers with many locations over a relatively short time, facilitating investigations at fine spatial and temporal scales (Johnson et al. 2008, Martin et al. 2009). Although this technology can be expensive and prone to biases (e.g., differential detection among habitats; Mattisson et al. 2010), GPS telemetry can be an effective tool for obtaining location information from animals that occur at low densities and often occupy inaccessible locations (Girard et al.

2002, Martin et al. 2009). However, such an approach may be impractical for studies addressing questions at large geographic scales (e.g., statewide), and are thus often constrained to a particular study area (Gompper et al. 2006). Additionally, the high cost of GPS telemetry collars often results in researchers sampling fewer individuals, resulting in weak inferences about a population (Hebblewhite and Haydon 2010).

Alternatives to GPS telemetry capable of addressing questions at large scales include camera traps, track-plates, scent stations, snowtracking, scat surveys, and incidental observations. Although these are all relatively inexpensive, they may be hindered by climate (i.e., snow needed for track surveys) and observer bias (Litvaitis et al. 1992, Gompper et al. 2006). Long et al. (2011) used scat surveys, hair snares, and camera traps to model habitat of black bears (*Ursus americanus*), fishers (*Martes pennant*), and bobcats (*Lynx rufus*) throughout Vermont. Observations by citizen volunteers can also occur over large geographic areas and at low cost (Quinn 1995, Gese 2001). For example, Kautz et al. (2000) used sightings to estimate realtive bobcat densities in portions of New York and Woolf et al. (2002) used sightings to estimate bobcat densities and habitat suitability in southern Illinois. Using a similar approach, Linde (2010) extrapolated a habitat model derived from information from bowhunter surveys to estimate bobcat distribution and relative abundance in Iowa.

There are a variety of assumptions and possible limitations associated with sightings data that may limit their utility, including accurate animal identification and restricted spatial and temporal sampling (Quinn 1995, Gese 2001, Wilson and Delahay 2001, Woolf et al. 2002). However, for rare or secretive species, sightings may be the only available source of data (Quinn 1995, Palma et al. 1999, Woolf et al. 2002), and such information is becoming more available due to increasing popularity of such devices as camera traps. For example, Balme et al. (2009) used camera-trap techniques to produce density estimates of leopards (*Panthera pardus*). These estimates were similar to those obtained from telemetry data, but at a considerably lower cost (Balme et al. 2009).

Regardless of the sampling approach, information on habitat selection can be used to develop predictive models in geographic information systems (GIS) (e.g., Clark et al. 1993, Lovallo et al. 2001, Woolf et al. 2002). These models can be constructed with information on geographic distribution and habitat requirements to predict relative abundance over large spatial scales (e.g., Wilson and Delahay 2001, Boyce et al. 2002). Such models would be valuable in New Hampshire, where little is known about the current abundance and distribution of bobcats. Bobcats have been protected in New Hampshire since 1989, and populations seem to be increasing (Litvaitis et al. 2006, Roberts and Crimmins 2010). Current information on bobcat distribution in the State is limited to incidental sightings and captures plus vehicle-related mortalities (Litvaitis et al. 2006).

Based on the lack of information on bobcat habitat needs and abundance in New Hampshire, I examined bobcat habitat use using two distinct approaches: GPS telemetry within a restricted study area and citizen observations from throughout the State. Data from these two approaches was then used to generate habitat models and habitat-suitability maps. Models were compared to determine if there was agreement among covariates. If comparisons between the models and their outputs suggest similarity, sightings models could be deemed a valuable and economical tool with by which to assess the status of bobcats over a large area at modest costs.

Organization of Following Chapters

In Chapter II, I examined bobcat habitat use by comparing habitat models developed using GPS telemetry and citizen observations. I then used the most biologically supported habitat model and several approaches to construct estimates of potential abundance and present the techniques and abundance estimates in Chapter III. Each technique included information on bobcat habitat requirements and produced estimates of statewide bobcat carrying capacity. Habitat information introduced in Chapter II and abundance estimates introduced in Chapter III were interpreted and used to make suggestions relevant to monitoring and managing bobcats within the State and presented in Chapter IV.

CHAPTER II

COMPARISON OF BOBCAT HABITAT MODELS IN NEW HAMPSHIRE

Identifying wildlife-habitat associations is necessary for the conservation and management of a species (Boyce and McDonald 1999, Manly et al. 2002). Such information can be used to develop predictive models of relative animal abundance in geographic information systems (GIS) (e.g., Clark et al. 1993, Lovallo et al. 2001, Nielsen and Woolf 2002). These models would be valuable in New Hampshire, where little is known about the current abundance and distribution of bobcats. Bobcats have been protected in New Hampshire since 1989, and populations seem to be increasing as suggested by a recent increase in incidental sightings and captures plus vehicle-related mortalities (Litvaitis et al. 2006).

To identify bobcat-habitat associations, a variety of approaches are available to identify biotic and abiotic features that affect the distribution and abundance of a particular species. Sampling techniques used to identify wildlife-habitat associations and habitat selection that are limited to small focal areas include direct sampling techniques that often include captures and telemetry (Litvaitis et al. 1992). Global positioning system (GPS) telemetry provides researchers with many locations over a relatively short time (Johnson et al. 2008, Martin et al. 2009) and can be an effective tool for obtaining location information from animals that occur at low densities and often occupy inaccessible locations (Girard et al. 2002, Martin et al. 2009). However, limitations of telemetry include addressing questions at large geographic scales (e.g., statewide), the high cost of GPS telemetry collars often results in researchers sampling fewer individuals (Hebblewhite and Haydon 2010), and bias can occur due to a differential detection among habitats (Mattisson et al. 2010).

Alternative techniques to radio telemetry capable of addressing questions at large scales include camera traps and surveys/reported observations. However, these inexpensive approaches have limitations such as observer bias (Litvaitis et al. 1992, Gompper et al. 2006), but for rare or secretive species, sightings may be the only available source of data (Quinn 1995, Palma et al. 1999, Woolf et al. 2002) and such information is becoming more available due to increasing popularity of such devices as camera traps. Use of such techniques has been reported in Illinois (Woolf et al. 2002) and Iowa (Linde 2010) where bobcat sightings were used to construct predictive-statewide habitat models. Those studies assessed the practicality of their techniques by comparing their estimates to independent data sources (e.g. additional sightings; Woolf et al. 2002) or the covariates of previously composed models (Linde 2010). However, no direct comparison was made between predictions of their sightings-based habitat model and predictions from a direct sampling-based (e.g. telemetry) habitat model.

Intensive sampling designs have been the norm for monitoring carnivore species, but researchers are always looking for inexpensive and efficient methods to monitor all wildlife, especially at larger scales (Gompper et al. 2006). The focus of this Chapter was to determine if bobcat habitat selection could be identified using inexpensive and abundant citizen sightings by comparing that technique and its outputs with GPS telemetry, an intensive sampling technique.

METHODS

Habitat Model Based on Telemetry

Study Area. Bobcats were captured in an approximately 1,800-km^2 region of southwest New Hampshire (New Hampshire Fish and Game Wildlife Management Unit H2). This area had the greatest historical harvests and number of recent sightings (Litvaitis et al. 2006). Dominant overstory species includes eastern hemlock *(Tsuga canadenesis)*, eastern white pine *(Pinus strobus)*, American beech *(Fagus grandifolia)*, yellow birch *(Betula alleghaniensis)*, paper birch *(Betula papyrifera)*, northern red oak *(Quercus rubra)*, red maple *(Acer rubrum)*, and sugar maple *(Acer saccharum)*. Topography is moderately rugged with elevation reaching 965 m above sea level at the peak of Mt. Monadnock. Average annual snowfall is between 127-178 cm and average annual temperatures are -6° C in the winter and 15° C in the summer (NOAA Climate Services, 2011). Human population density is approximately 42/km^2 (Cheshire County, NH, 2010 Census Data; US Census Bureau, 2011). Maintained road density within the study area is 1.4 km/km^2.

Capture and Monitoring. Private trappers were contracted by New Hampshire Fish and Game Department from November 2009 to March 2010 and bobcats were captured with baited box traps. Adult size bobcats were anesthetized with an intramuscular injection of ketamine HCl and xylazine HCl (5:1, 10 mg/kg) (Tucker et al.

2008). Gender was determined and approximate age was based on weight and tooth condition. Animals weighing less than 4.5 kg and showing little sign of tooth wear or gum recession were classified as juvenile and released. A vestigial molar was extracted to determine exact age by cementum analysis (Crowe 1975). Males weighing more than 9.0 kg and females weighing more than 6.5 kg were equipped with a numbered ear tag and a Global Positioning System (GPS) radiocollar. GPS collars included Sitrack drop-off collars (Internal Release, 220g, Sirtrack Limited, Havelock North, New Zealand) and Lotek Wildcell collars (Wildcell, 270g, Lotek Wireless, Newmarket, Ontario, Canada). Tissue samples and morphometric measurements were obtained and individuals then received a subcutaneous penicillin injection and an intravenous injection of reversal (yohimbine). Bobcats were released on site once they fully recovered. All study animals were handled in accordance with University of New Hampshire Institutional Animal Care and Use Committee (Protocol #081201, Appendix A).

Attempts were made to locate bobcats within 36 hours of release to confirm that the collar was functioning and that the bobcat was active. General locations of bobcats were obtained every 2-8 weeks via ground telemetry or fixed-wing aircraft and yagi antennas. These locations were not included in subsequent analysis. When a collar VHF signal indicated mortality or collar release, ground telemetry and homing were used to locate and recover the collar. Bobcats with auto-release collars that failed to drop off were recaptured the following winter (2010-2011) using the same protocol as initial captures.

Both collar models include VHF and GPS capabilities as well as a timed mortality beacon. Sitrack and Lotek GPS collars obtained a fix every 7 and 5 hours, respectively.

Locations were downloaded from Sitrack collars after dropoff (September 1, 2010), whereas the Lotek collars sent locations via short message services (SMS messages) to a receiving ground station. A screening technique was used that removed GPS locations of high error due to poor satellite geometry. The number of satellites used in obtaining a GPS location is indicated by a fix being 2-dimensional (3 satellites) or 3-dimensional (≥ 4 satellites). A measurement of accuracy (positional dilution of precision: DOP) also accompanied each GPS location. As GPS location error increases with fewer satellites and increasing DOP, my screening technique consisted of removing 2-dimensional (2D) fixes with a dilution of precision greater than 5.0 (Lewis et al. 2007). This technique was selected because it removed highly inaccurate locations while retaining as much data as possible.

Home Range Estimation. Composite home ranges were calculated using a fixed kernel density estimator with least squares cross-validation used for bandwidth selection (Worton 1989, Seaman and Powell 1996, Millspaugh et al. 2006) using the Home Range Extension (Hooge and Eichenlaub 1997) for ArcView 3.3 (Environmental Systems Research Institute, Redlands, CA, USA). Home ranges were based on a minimum of 30 locations (Seaman and Powell 1996) and 95% utilization distributions (UD) and core areas (50% UD, Powell 2000, Tucker et al. 2008) were plotted.

Taking into account bobcat behavior, annual climate change in New Hampshire, and data availability, bobcat GPS data was also divided into three seasons (Winter, 1-Nov through 31-Mar; Spring rearing, 1-Apr through 15-June; and Summer, 16-June through 31-Oct) and seasonal home ranges and core areas were estimated using the same techniques (Appendix B).

Habitat Modeling. Bobcat habitat selection was based on resource selection functions (RSF) and a use vs. available design fit to a logistic regression function (Boyce et al. 2002, Manly et al. 2002). Resource selection in this design is defined as using a habitat feature disproportionately to its availability. Habitat features consisted of 37 categorical or continuous measurements and were considered as immediate and proximity measurements (Table 1). Immediate habitat measurements included such measurements as land cover type, slope, elevation, and snowfall, whereas proximity measurements included such measurements as road density, distance to stream, and distance to light development.

Common limitations to the use of remotely-sensed digital habitat data include identification of sub-canopy features and outdated data. Thus, one such feature I was unable to directly identify were ledges (i.e., rocky outcroppings that often run in a northwest to southeast direction) because the locations of these features did not occur in any digital form that could be used for this analysis. These rugged areas can serve as loafing sites (Anderson 1987), escape cover (Anderson 1987, Koehler and Hornocker 1991, Apps 1996), hunting sites (Koehler and Hornocker 1989, Apps 1996), and denning sites (Bailey 1974) for bobcats. Temporal limitations of GIS layers are highlighted when examining scrubland habitats. In New Hampshire, the shrub/scrub land cover often represents regenerating timber harvests and power line right-of-ways that consist of early-successional vegetation. Unlike landscape features such as topography and relatively unchanging land uses (i.e., wetlands, roads, streams, etc.), forest management and timber harvest is a dynamic process that continuously changes the landscape.

Implications of Scale. Assessing habitat selection at multiple scales simultaneously can provide a more complete impression of habitat preference (Boyce 2006, Mayor et al. 2009), so I examined selection at 2 spatial orders (Johnson 1980) using 3 methods of analysis. Second order habitat selection compared habitat use within home ranges versus available habitat within the study area. Two methods of analysis occurred at the third order: habitat use at bobcat locations versus available habitat within home ranges and habitat use within core areas versus available habitat within home ranges. Use versus available comparisons followed a sampling design of 1:1. For bobcat locations versus home-range models, bobcat locations were compared to an equal number of randomly generated locations within each home range to represent available habitats. Obtaining 'used' locations when comparing areas of use (e.g., core areas and home ranges) consisted of generating 100 random locations within the area of use and 100 random locations within the area of availability (Manly et al. 2002). When examining habitat selection at the home range scale, the study area was defined as a minimum convex polygon around all bobcat locations. All random locations were generated using Hawth's Analysis Tools (Beyer 2004) in ArcGIS 9.3.

These analyses were applied to composite and seasonal home ranges (Appendix C); however, only composite home ranges are discussed in this Chapter.

Data Evaluation. Prior to model development, a Spearman rank correlation was used to identify collinearity between continuous variables. If $r \geq 0.70$, the more biologically meaningful habitat variable was retained (Appendix D; Saher and Schmiegelow 2005).

Locations obtained from GPS collars can be highly correlated in time and space (Boyce 2006, Dormann et al. 2007). This violates the assumption of independence among observations (Hosmer and Lemeshow 2000, Boyce 2006) and may lead to inaccurate estimates of variance (Otis and White 1999) and an increased chance of committing a Type-I error (i.e., concluding that a pattern or relationship exists when in reality one does not; Boyce 2006). To address this, individual bobcats were used as a random intercept in a mixed-effect model to allow for spatial autocorrelation between locations and unbalanced numbers of locations (Breslow and Clayton 1993, Gillies et al. 2006). Previously, researchers would censor data until statistical independence was met to account for temporal autocorrelation (e.g., destructive sampling, Swihart and Slade 1985). However, that approach negates the benefits of advanced GPS telemetry that is capable of providing large datasets to address detailed questions in wildlife behavior and ecology (Cagnacci et al. 2010). In many telemetry studies, large quantities of data must be censored to satisfy statistical independence (Gillies et al. 2006). Rather than discard data, I considered use of autocorrelation functions (Diggle 1990); however, such an approach may not be used with telemetry data from GPS devices set to different fix rates (i.e., GPS fix schedules set to different time lags between fixes) or when failed fix attempts result in missing data (as in this study). Next, I considered incorporation of temporal correlation into the model. However, the statistics package used (lmer function in lme4 package, Bates et al. 2011; in R, R Development Core Team 2011) did not permit the inclusion of such correlations in the model framework. The issue of autocorrelation is acknowledged as problematic (Dormann et al. 2007, Boyce et al. 2010, Fieberg et al. 2010). I elected not to account for temporal autocorrelation and contend information derived from large datasets were more valuable than information derived from statistically independent yet substantially smaller datasets.

The systematic loss of GPS locations due to habitat features inhibiting satellite communication (GPS bias) was addressed by weighting locations by the inverse probability of successfully acquiring a GPS fix (Friar et al. 2004, Hebblewhite et al. 2007). I was unable to conduct collar tests as collars were deployed shortly after they were received from the manufacturer, so I relied on information generated by Mallett (2012) in nearby Maine. Mallett's (2012) raw collar test data enabled me to calculate the probability of acquiring a GPS fix (*Pfix*) for 3 of my land cover types (light development, shrub/scrub, and softwood) using logistic regression to model the probability of a fix attempt being successful (1) or unsuccessful (0). For example, *Pfix* for softwood was 0.84 and locations in that cover were weighted by a value of 1.19. Locations in light development were weighted by 1.01, shrub/scrub by 1.18, and all other land cover types by 1.00. These weights ultimately had little influence on model fitness and training.

<u>Model Training and Testing.</u> Akaike Information Criterion (AIC) values were used to determine the best fitting models. I used the top 6-8 best fitting univariate models (e.g., lowest AIC values) to develop multivariate models using every possible combination of the top variables. Selecting the best fitting models (i.e., ranking by AIC) adhered to Burnham and Anderson's (2002) suggestion of selecting the most parsimonious model when $\Delta AIC \leq 2.0$ (e.g., the model with fewer variables). For the set of multivariate models developed at a specific scale, ΔAIC and 95% model confidence set were calculated. To calculate a confidence set for candidate models (i.e., 95% model confidence set, Burnham and Anderson 2002), I started with the AIC weight of the top

Table 1. Habitat variables used in GIS and justification for use. Asterisk (*) indicates variables removed due to high collinearity ($r \geq 0.7$).

Habitat Measurement (units)	Justification	GIS Data Source
Elevation (m)	Bobcats prefer areas of low elevation (Lovallo and Anderson 1996)	USGS Digital Elevation Model (DEM)
Slope (degrees)*	Bobcats have been found in ledges and areas of high slope (McCord 1974)	DEM Spatial Analyst calculation
Aspect (Flat, N, NE, E, SE, S, SW, W, NW)	Aspect influences sun exposure and consequently snow depth and vegetation	DEM Spatial Analyst calculation
Landcover (Open Water, Light Development, Heavy Development, Disturbed/Bareground, Mixedwood, Softwood, Shrub/Scrub, Agriculture, Wetland)	Bobcats prefer particular land cover types (Freeman 2010)	2006 National Land Cover Dataset (2006 NLDC) collapsed into 9 categories deemed similar to bobcats
Snowfall (mm)	Snowfall has negative impacts on movement and survival (Litvaitis et al. 1986)	Spatial Analyst calculation- Sum of mean winter month precipitation (Oct-Mar) from 1971-2000
Vector Ruggedness Measurement	Bobcats have been found in ledges and rugged terrain (McCord 1974)	VRM Tool calculation that uses slope and aspect to produce ruggedness value (Sappington et al. 2007)
Road Density (km/km^2) Density all roadways, all Road Classes	Roads have a negative impact on bobcat survival (Litvaitis and Tash 2008)	Spatial Analyst calculation using a search radius of 1.3 km (mean daily absolute distance traveled by monitored bobcat)
Highway Density (km/km^2)- Density of Class 1 & II roads (i.e. large, high traffic roadways)	Highways have a negative impact on bobcat survival (Litvaitis and Tash 2008)	Spatial Analyst calculation using a search radius of 1.3 km (mean daily absolute distance traveled by monitored bobcat)
Stream Density (km/km^2)- Density of all Stream Orders	High stream densities seem to be associated with areas of high historical harvest in New Hampshire	Spatial Analyst calculation using a search radius of 1.3 km (mean daily absolute distance traveled by monitored bobcat)
River Density (km/km^2)- Density of Stream Orders ≥ 3 (i.e. wide waterways not easily crossed by bobcats)	High river densities seem to be associated with areas of high historical harvest in New Hampshire	Spatial Analyst calculation using a search radius of 1.3 km (mean daily absolute distance traveled by monitored bobcat)
Distance to Edge (m)	Forest edge can be a source of high prey abundance and a travel corridor for predators.	Landscape Fragmentation Tool (Vogt et al. 2007) and Analysis Tool calculation

(Table 1 cont'd)

Habitat Measurement	Justification	GIS Data Source
Distance to Stream (m)- Nearest stream of any Stream Order	Bobcats prefer riparian habitats (Woolf et al. 2002, Tucker et al. 2008)	NH Digital Flowline and Analysis Tool calculation
Distance to River (m)- Nearest stream with a Stream Order ≥ 3 (i.e. wide waterways not easily crossed by bobcats)	Bobcats prefer riparian habitats (Woolf et al. 2002, Tucker et al. 2008)	NH Digital Flowline and Analysis Tool calculation
Distance to Road (m)- Nearest roadway of any Road Class	Roads have a negative impact on bobcat survival (Litvaitis and Tash 2008)	All NH & VT Road layers and Analysis Tool calculation
Distance to Highway (m)*- Nearest roadway of Road Classes 1 or 2 (i.e. large, high traffic roadways)	Highways have a negative impact on bobcat survival (Litvaitis and Tash 2008)	NH & VT Road layers and Analysis Tool calculation
Distance to Open Water Land Cover (m)	Proximity may indicate access to open water	2006 NLCD and Analysis Tool calculation
Distance to Light Development Land Cover (m)*	Proximity measurement may indicate avoidance of developed areas	2006 NLCD and Analysis Tool calculation
Distance to Heavy Development Land Cover (m)	Proximity measurement may indicate avoidance of developed areas measurement accounted for this	2006 NLCD and Analysis Tool calculation
Distance to Disturbed/Bareground Land Cover (m)	Proximity measurement may indicate avoidance of disturbed areas	2006 NLCD and Analysis Tool calculation
Distance to Shrub/Scrub Land Cover (m)	Proximity may indicate access to scrublands	2006 NLCD and Analysis Tool calculation
Distance to Agriculture Land Cover (m)	Proximity may indicate access to agriculture	2006 NLCD and Analysis Tool calculation
Distance to Wetland Land Cover(m)	Proximity may indicate access to wetlands	2006 NLCD and Analysis Tool calculation

ranking model and added the AIC weights of the next highest ranking models until the sum reached 0.95. The number of competing models used to reach that sum was the 95% confidence set, and the higher the set value the higher the uncertainty associated with determining the best fit model.

Validation of the top multivariate models was done using a *k*-fold cross-validation technique that evaluates a model on its ability to predict animal locations (Boyce et al. 2002, Johnson et al. 2006). This technique consisted of randomly partitioning data into *k* subsets and then conducting iterative model training and testing (Boyce et al. 2002) using a normalized, equal-area, moving-window average binning technique (Wiens et al. 2008). The products of the *k*-fold cross validation technique (i.e., mean fold Spearman rank correlation coefficient 'r_s', standard deviation, and *p*-value) were used to identify the best predictor model (Wiens et al. 2008).

Development of Statewide Map of Suitable Habitats Based on Telemetry Locations. The best predictor RSF model examining core area habitat selection was used to develop a map of bobcat habitats because it is often assumed that core areas encompass the highest densities of resources and are more important to an animal than other portions of its home range (Powell 2000). This scale also appeared to be the best scale for analysis using reported sightings. RSF values were normalized (0 to 1) producing a relative probability of use for each 90x90 m map unit in New Hampshire. I defined suitable habitat as map units with a RSF ≥ 0.5 (Burdett et al. 2010).

As map units are relatively small (8,100 m^2), it was difficult to comment on the distribution of suitable habitats at the statewide scale (Figure 1). Therefore, I examined the quantity of suitable habitat within New Hampshire 6th level (12-digit Hydrologic Unit Code) subwatersheds (USGS et al. 2011). I could have used other measurements, such as percent composition of suitable habitat within subwatersheds, but quantifying the amount of suitable habitat was a better aid for identifying areas with large or small amounts of suitable habitat. As the name implies, subwatersheds are sub units of watersheds and were selected as a unit of area because they are considerably larger than 90x90 m map units (in New Hampshire n =327, $\bar{x}$ =87.3 km^2, SD=36.0), allowing for model comparisons to be made at the landscape scale but still small enough to identify differences in suitable habitat abundance and distribution. The boundaries of subwatersheds are also much less subjective than township or county boundaries because they are delineated by surface drainage basins. Linde (2010) used subwatersheds as a scale of habitat analysis and comparisons for many of the same reasons, but also suggested these subwatersheds or drainages are visible to bobcats on the landscape and may serve as corridors or barriers to movement.

The location-telemetry model might also be a valuable approach for modeling statewide habitat as it had the most objective sampling design because used locations consisted of GPS locations and not locations randomly generated within an area of use. As a result, I developed a habitat suitability map and suitable habitat by subwatershed map using the location model as an additional source for identifying statewide suitable habitat.

Habitat Model Based on Citizen Observations

Bobcat observations were solicited from a project-based website (http://mlitvaitis.unh.edu/Research/BobcatWeb/bobcats.htm). Locations from May 2008 through February 2011 were ranked from 1-3 based on my ability to locate them on a map. Sightings that contained a house address or geographic coordinates received a rank of 1. Those that included more general descriptions such as a distance from a major intersection were ranked a 2. Sightings that contained only a general location (e.g., 'sighted on Route 4' or 'Deerfield Township') received a rank of 3. Only locations ranked a 1 or 2 were used in analysis.

Each sighting location was likely the product of a bobcat preferring an immediate or proximate habitat feature. To determine habitat selection in that area, analysis occurred at a scale similar to the core-area telemetry model (third order habitat selection) where habitat use within a core area was compared to available habitat within a home range. Following that design, circular buffers were centered on each sighting location (Johnson et al. 2006, Atwood and Gese 2010) that were equal to the area of a core area (2.5 km^2) and home range (29.7 km^2) of a female bobcat observed in this study (Appendix B) and within the range of female home ranges observed in adjacent states (Maine = 33 km^2, Litvaitis et al. 1986; Vermont = 22.9 km^2, Donovan et al. 2011). Used and available locations were obtained by generating 100 random points within the core area and home range buffers. All 37 habitat measurements were obtained in GIS for every used and available location. Variable screening and sightings model development and validation followed procedures for the habitat model based on telemetry locations except that the random effect was now each sighting and there was no sample weighting.

Development of a habitat suitability map also followed the methods using telemetry locations.

Evaluation of Habitat Models

A comparison of model selection confidence between the top core-area and sightings models was assessed using 95% model confidence sets and comparisons of predictability was assessed using mean Spearman rank correlation coefficients. I compared model covariates to determine if there was any similarities, and if so, was the relationship between shared covariates consistent (i.e., was the sign of the coefficients the same between shared covariates). I then compared habitat suitability maps with recent sightings. To determine if there is agreement on the distribution and abundance of suitable habitat between the telemetry model and the sightings model, I first ranked subwatersheds by the amount of suitable habitat for each model. For the 50 highest and 50 lowest subwatersheds identified by the telemetry model, I tallied the number of subwatersheds that were also present in the 50 highest and 50 lowest subwatersheds according to the sightings model. The amount of overlap (i.e., large or small number of similar subwatersheds) indicated the level of agreement between models on areas with high or low amounts of suitable habitat. For example, if the telemetry model and sightings model suggested the same 50 subwatersheds contain the most suitable habitat, then I would conclude that these models agree on the areas with the greatest amount of suitable habitat.

RESULTS

Twelve adult bobcats (10 M, 2 F) were captured and fitted with GPS collars (Appendix E). Data were obtained from 11 (10 M, 1 F), with 115-970 locations per individual. After screening for error, 4,583 locations spanning November 2009 to December 2010 were available for analysis (Appendix F). Mean composite home ranges and core areas for males were 93.5 km^2 and 11.6 km^2, respectively, whereas those for the female were 29.7 km^2 and 2.5 km^2 (Figure 1, Appendix B). The minimum-convex polygon generated by using all bobcat locations served as the effective study area for investigating habitat selection at the home-range scale was 2,257.9 km^2 (Figure 2).

Habitat Model Based on Telemetry

Top predictor models for the GPS location, core area, and home-range scales were among the top ranking AIC multivariate models at each scale as indicated by low ΔAIC scores (Table 2). That indicated the top predictor models also had good fit. In the *k* fold technique, the number of bins is arbitrary (Pearce and Boyce 2006, Wiens et al. 2008) so I started with 6 bins. However, when technique outputs (i.e., mean Spearman correlation coefficient (r_s), standard deviation, and p-value) for competing multivariate models were identical, I increased the number of bins to 10 and repeated the technique to observe a difference between outputs. Such was the case for the core-area model and therefore, only general comparisons of *k*-fold technique outputs between spatial scales could be made.

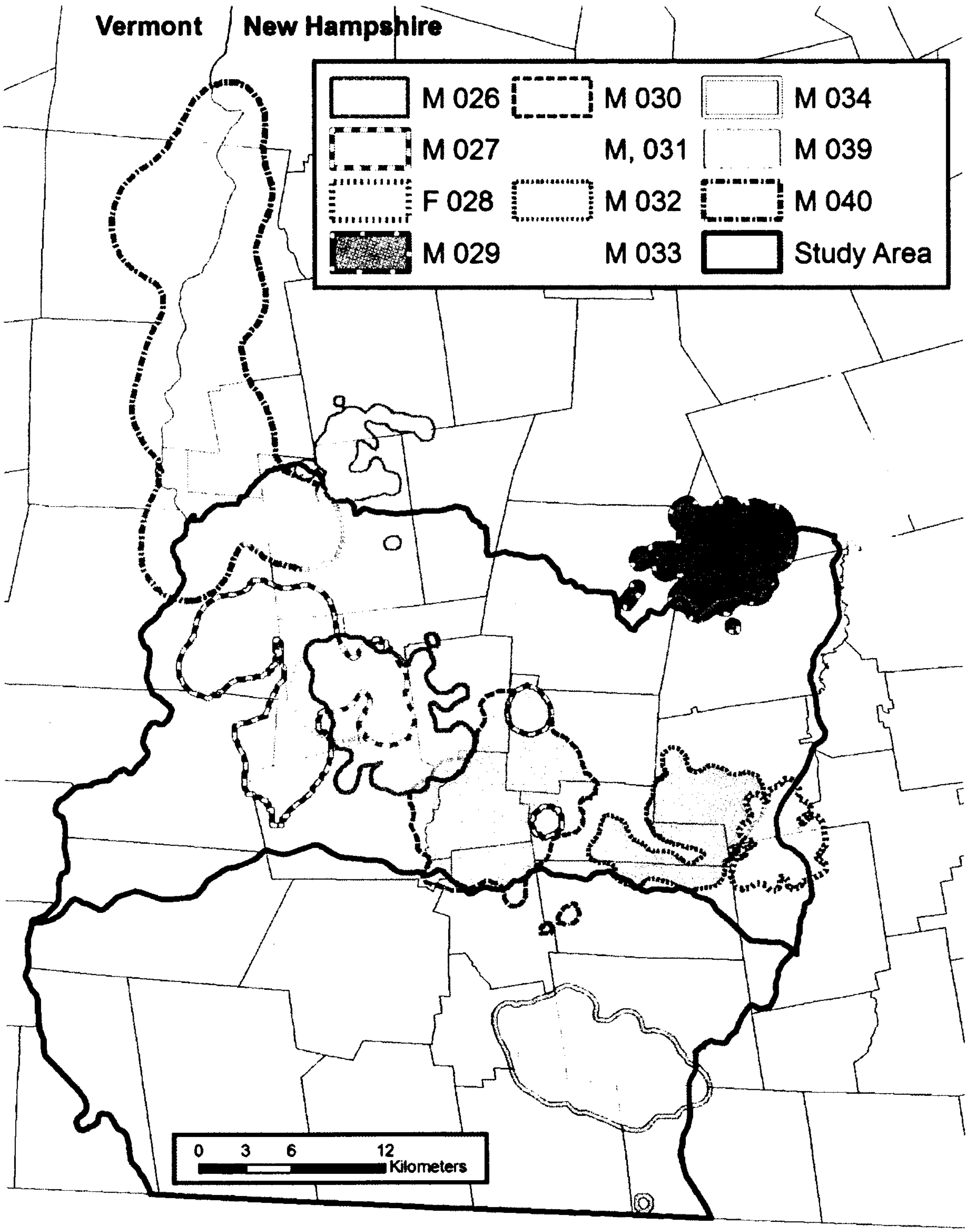

Figure 1. Composite home ranges of 11 GPS collared bobcats (10 M, 1 F) in southwest New Hampshire within New Hampshire Fish and Game Wildlife Management Unit H2 (dark outline). Home ranges were calculated using a fixed-kernel density estimator and bobcat locations from November 2009 to December 2010.

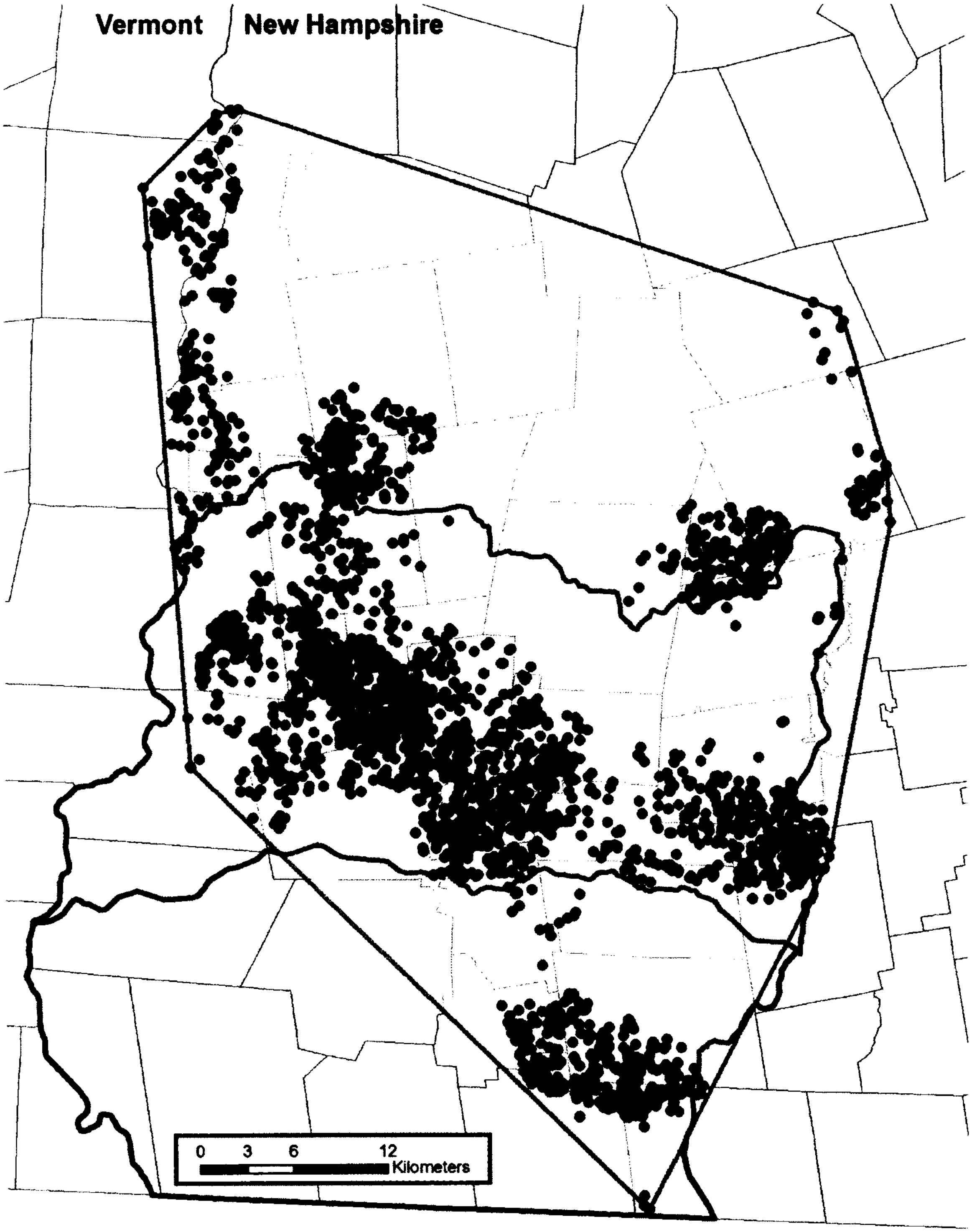

Figure 2. Minimum-convex polygon (2,257 km^2) in southwest New Hampshire created around bobcat locations obtained from November 2009 to December 2010. Minimum-convex polygon was used in the home range telemetry habitat selection model.

Table 2. Fit and predictability for each habitat selection model developed using bobcat telemetry locations in southwest New Hampshire from November 2009 to December 2010 and statewide citizen sightings from May 2008 to February 2011. Values are for the best predictor model for each spatial scale, therefore 'Δ AIC score' is calculated from the best fit multivariate model in that scale and comparisons of that value and other habitat models should not be made. 95% model confidence set indicates the amount of certainty associated with selecting the best fitting models at that scale (i.e., higher numbers of models in the confidence set indicates higher model uncertainty). The closer model mean r_s value is to 1.0, the higher correlation between frequencies of RSF values and bin number and the higher the model predictability. Only models with the same number of bins can be compared, but in this case a higher bin number indicates better predictability.

				k-fold validation			
Habitat Model	***n* Variables**	**Δ AIC score**	**95% Model Confidence Set**	**Mean r_s**	**Mean SD**	**Mean *P***	**Bin Number**
GPS Location Telemetry	7	1.281	31	0.9556	0.0608	0.0019	6
Core Area Telemetry	7	0	6	0.7556	0.3734	0.0732	10
Home Range Telemetry	4	0.908	30	0.7662	0.2650	0.0537	6
Sightings	6	1.976	13	0.9857	0.0319	< 0.001	10

There were a large number of models in the location-telemetry model 95% model confidence set indicating high uncertainty in selecting the best fitting model; however the location model was good at predicting bobcat locations (Table 2). This model suggested bobcats selected for wetlands, scrublands, riparian areas, areas of low elevation, and used developed lands, mixedwoods, and northwest aspects less than they were available (Table 3). The core area habitat selection model predicted well based on *k*-fold outputs and had a small 95% model confidence set (Table 2). At this scale, bobcats selected areas at low elevations, low stream densities, and for wetlands (Table 3). Core areas also were characterized by longer distances from roads and forest edges, while heavily developed areas and east-facing slopes were used proportionally less than suggested by their availability. The top model at the home-range scale did not predict well and had a 95% model confidence set slightly less than the location-based model (Table 2). Home ranges encompassed areas of low elevation, low snowfall, and low stream density but in close proximity to agricultural fields, wetlands, and rivers (Table 3). This model also suggested home ranges were located in close proximity to highly-developed habitat.

Literature on other bobcat habitat studies seem to support the covariates of the location-telemetry model more than the other telemetry models and suitable habitat delineated by the model included 8,793 km^2 or 38% of the land area of New Hampshire (Figure 3). The distribution of suitable habitat by subwatershed was arranged such that subwatersheds that contained less suitable habitat occur in north central portions of New Hampshire (e.g., White Mountains regions) whereas subwatersheds in all other portions of the State contained greater amounts of suitable habitat (Figure 3).

The core-area telemetry model was used to compare the sightings model and suitable habitat delineated by the core-area model included 14,584 km^2 or 63% of the land area of the State (Figure 4). The distribution of suitable habitat by subwatershed was generally divided east and west. Subwatersheds in western New Hampshire contained less suitable habitat whereas subwatersheds in eastern New Hampshire contained higher amounts (Figure 4, Figure 5).

Table 3. Names, coefficients, standard errors, and *p*-values of habitat variables present in telemetry and sightings models. Telemetry models identify habitat selection at bobcat GPS locations, core areas, and home ranges from GPS telemetry data collected from November 2009 to December 2010 in southwest New Hampshire. The sightings model identifies habitat selection using solicited public sightings collected statewide from May 2008 to February 2011. All models were created using Resource Selection Functions following a used vs. available design.

	GPS Locations			Core Area			Home Range			Sightings		
Variable	**β**	**SE**	***P***	**β**	**SE**	***P***	**β**	**SE**	***P***	**β**	**SE**	***P***
Intercept	0.0815	0.0835	0.329	1.3070	0.2653	<0.001	2.9170	6.9430	<0.001	0.1968	0.0208	<0.001
Wetland	0.9976	0.0843	<0.001	0.5143	0.1968	0.009						
Mixedwood	-0.0791	0.0480	0.099							-0.0383	0.0200	0.056
Distance to Stream	-3.22E-06	1.28E-06	0.012									
Elevation	-1.39E-06	2.65E-06	0.601	-3.56E-05	5.91E-06	<0.001	-1.42E-05	6.66E-06	0.033			
Northwest Aspect	-0.1919	0.0679	0.005									
Scrubland	0.5345	0.1837	0.004									
Light Development	-0.2276	0.1022	0.026							-0.0013	0.0240	0.958
Distance to Road				4.84E-06	2.00E-06	0.016				-5.50E-06	4.04E-07	<0.001
Distance to Edge				4.66E-06	2.37E-06	0.050				-4.98E-06	5.59E-07	<0.001
Heavy Development				-14.78	539.8	0.978						
Stream Density				-3.56E-05	9.75E-06	<0.001	-4.63E-05	1.02E-05	<0.001			
East Aspect				0.1811	0.1158	0.118						
Distance to Agriculture							-1.30E-06	1.20E-06	0.279	-1.90E-06	1.88E-06	<0.001
Distance to Heavy Development							-4.27E-07	2.96E-07	0.150			
Distance to River							-1.12E-06	8.06E-07	0.165			
Distance to Wetland							-2.90E-06	1.38E-06	0.035			
Snowfall							-2.30E-05	1.19E-05	0.053			
Highway Density										1.99E-05	1.88E-03	<0.001

Habitat Model Based on Citizen Observations

A total of 411 sightings were reported from 162 townships and were reported consistently over the span of solicitation. 298 were ranked 1 or 2 and used in analysis. . Like the core-area model, bin number was increased from 6 to 10 during *k*-fold validation to observe differences in technique outputs between competing multivariate models. The sightings model predicted well based on *k*-fold outputs and had a low 95% model confidence set (Table 2). The resulting model suggested bobcats selected areas close to agriculture, forest edge, roads, and areas with high highway density. This model also indicated mixedwoods and light development were used less than expected (Table 3).

Suitable habitat as delineated by the sightings-based model included 16,685 km^2 or 72% of the land area of the State (Figure 4), 12% more than the core-area model (14,584 km^2). The distribution of suitable habitat by subwatershed in the State was generally divided north and south. Subwatersheds in northern New Hampshire contained less suitable habitat whereas subwatersheds in southern New Hampshire contained higher amounts (Figure 4, Figure 5).

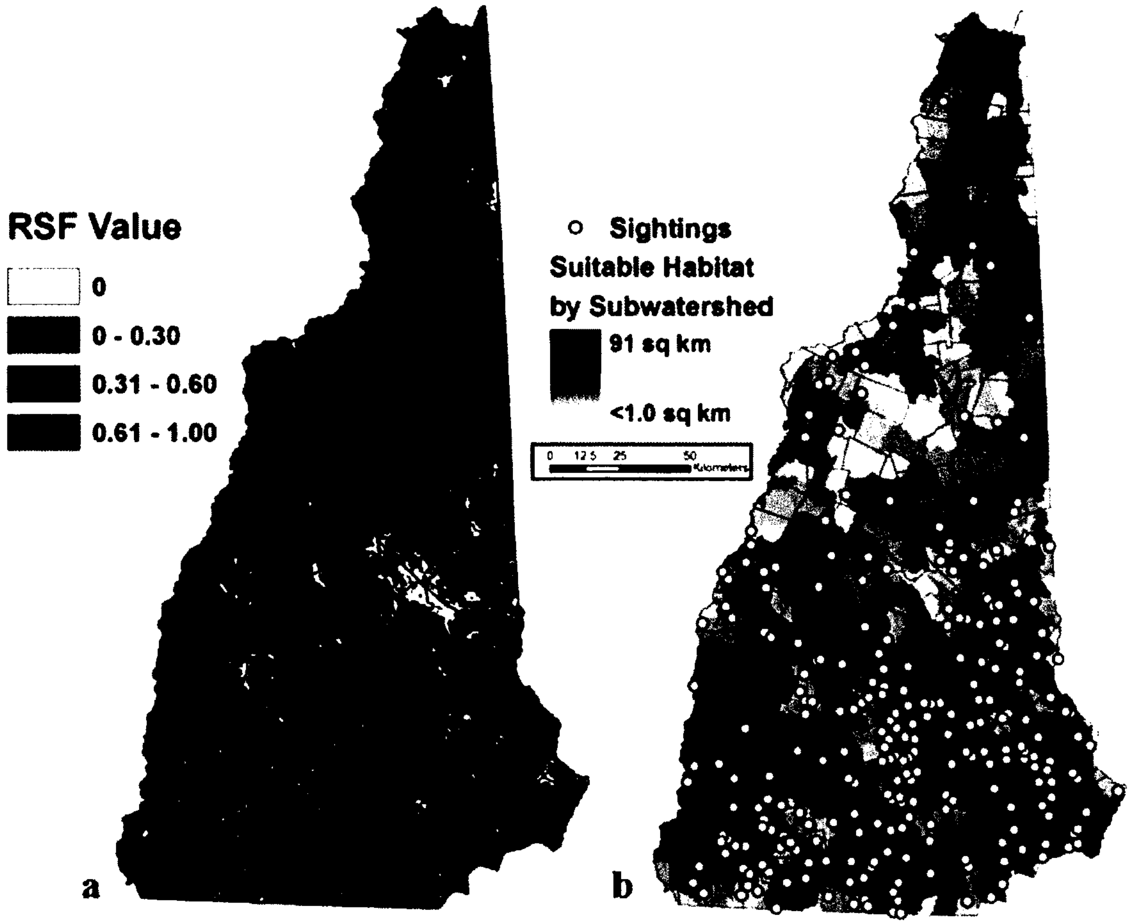

Figure 3. Bobcat habitat-suitability map (a) and recent bobcat sightings and the amount of suitable habitat per subwatershed (b) in New Hampshire for the location-telemetry model. The location-telemetry model was developed using GPS telemetry locations from bobcats in southwest New Hampshire from November 2009 to December 2010. The bobcat habitat-suitability map was constructed by calculating a resource selection function (RSF) value for each 90 x 90 m map unit. RSF values are the relative probability of habitat use by bobcats in New Hampshire and were assumed to indicate habitat suitability with habitats increasing in suitability as RSF approaches 1.0. Subwatersheds were selected as a unit of area because they are small enough to identify subtle differences in suitable habitat abundance and distribution and less subjective than township or county boundaries.

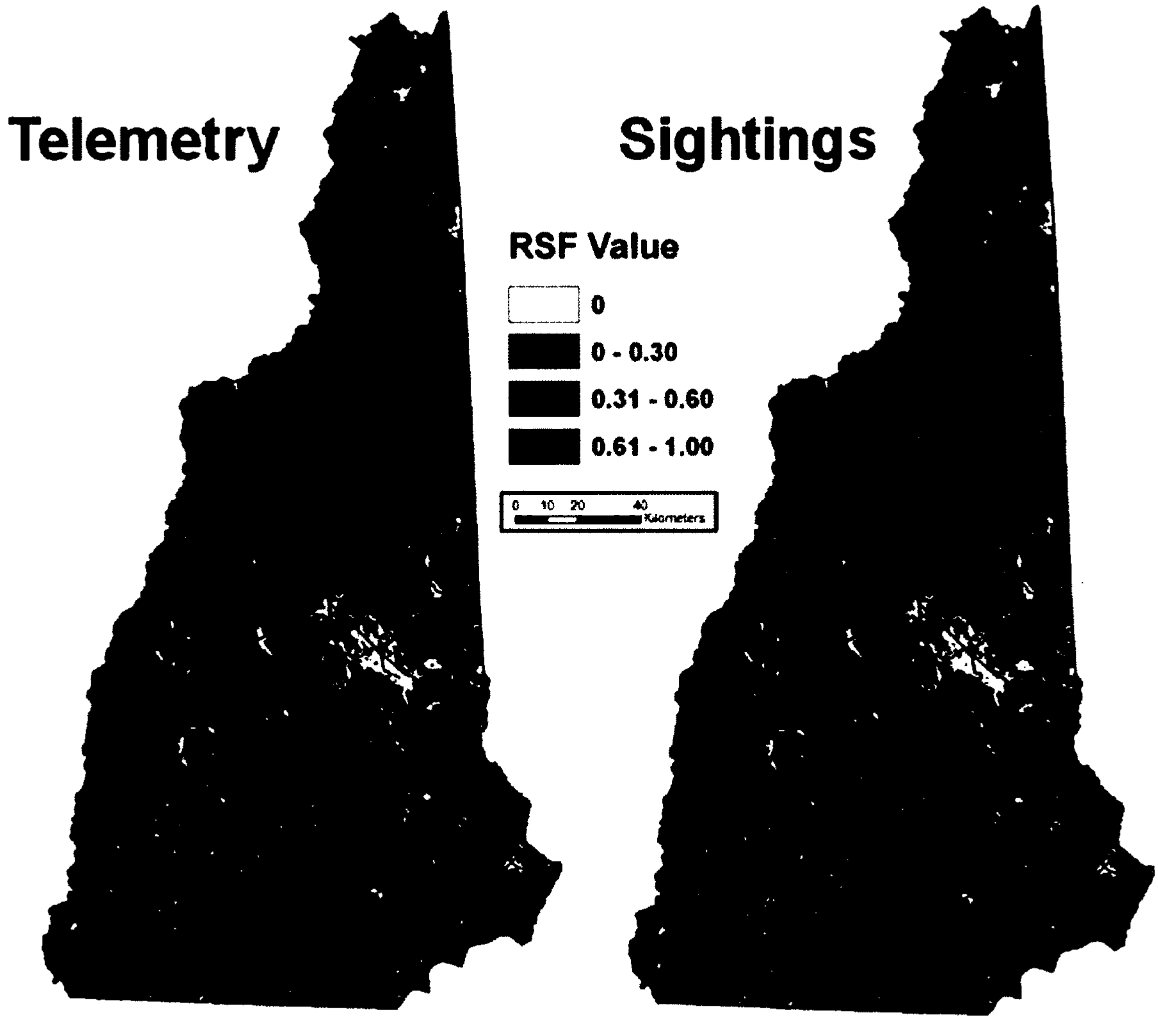

Figure 4. Bobcat habitat-suitability maps for the core-area telemetry model and sightings model. The core-area model was developed using location data from bobcats in southwest New Hampshire from November 2009 to December 2010. The sightings model was developed using statewide solicited sightings from May 2008 to February 2011. Maps were constructed by calculating a resource selection function (RSF) value for each 90 x 90 m map unit. RSF values are the relative probability of habitat use by bobcats in New Hampshire and were assumed to indicate habitat suitability with habitats increasing in suitability as RSF approaches 1.0.

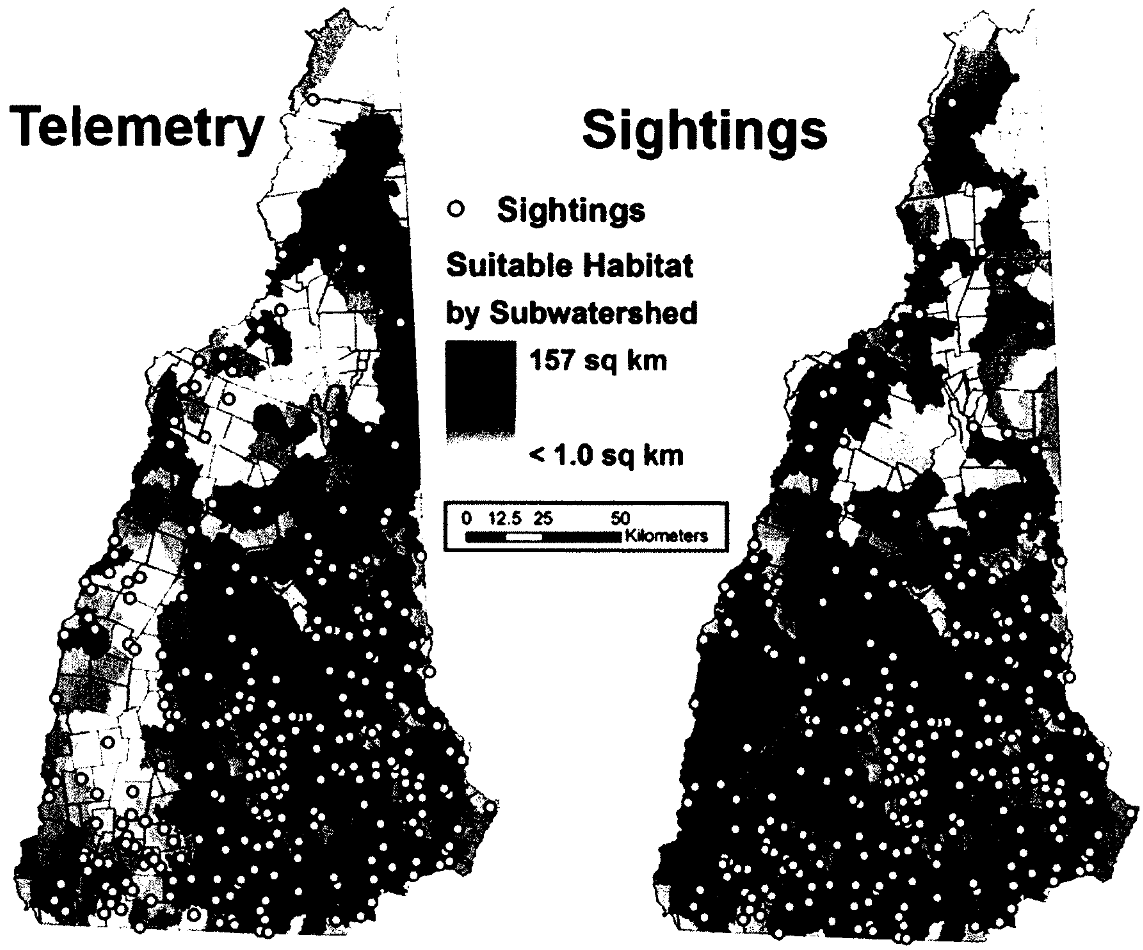

Figure 5. Recent bobcat sightings and the amount of suitable habitat per subwatershed for the core-area telemetry model and sightings model. The core-area model was developed using location data from bobcats in southwest New Hampshire from November 2009 to December 2010. The sightings model was developed using statewide solicited sightings from May 2008 to February 2011. Suitable habitat is defined as map units (90 x 90 m cells) with a RSF ≥ 0.5. Subwatersheds were selected as a unit of area because they are small enough to identify subtle differences in suitable habitat abundance and distribution and less subjective than township or county boundaries.

Evaluation of Habitat Models

The core-area telemetry and sighting-based models contained 2 of the same covariates (distance to road and distance to forest edge); however, the sign of the coefficients differed. The telemetry model indicated selection for areas at greater distance from roads and edges whereas the sightings data indicated selection for areas closer to roads and edges (Table 3). The sightings model was better at predicting 'use' locations (mean r_s 0.986, *SD* 0.032) than the telemetry model (mean r_s 0.756, *SD* 0.373, Table 2). This may have been due to the sampling design consisting of 59,600 data points (100 used and 100 available points for 298 observations) compared to 2,200 for the telemetry model (100 used and 100 available points for 11 monitored bobcats). However, the 95% model confidence set was much smaller for the core-area models (n = 6) compared to the sightings models (n = 13), indicating that there is more certainty in selecting the best-fitting telemetry model amongst competing core-area telemetry models than when selecting the best-fitting sightings model (Table 2).

Although there are some differences among models, both indicated the greatest density of suitable habitat occurred in central New Hampshire and the lowest densities occurred in northcentral portions of the State (e.g., White Mountains regions) (Figure 4 and Figure 5). Recent reported sightings occurred in or near subwatersheds identified as having high amounts of suitable habitat according to the sightings model, and the telemetry model was also good at predicting recent sightings (Figure 5). The sightings model agreed with 32 of the 50 (64%) subwatersheds the telemetry model depicted as containing the most suitable habitat but only agreed with 23 of the 50 (46%) of the subwatersheds the telemetry model depicted as containing the least amount of suitable habitat (Figure 6).

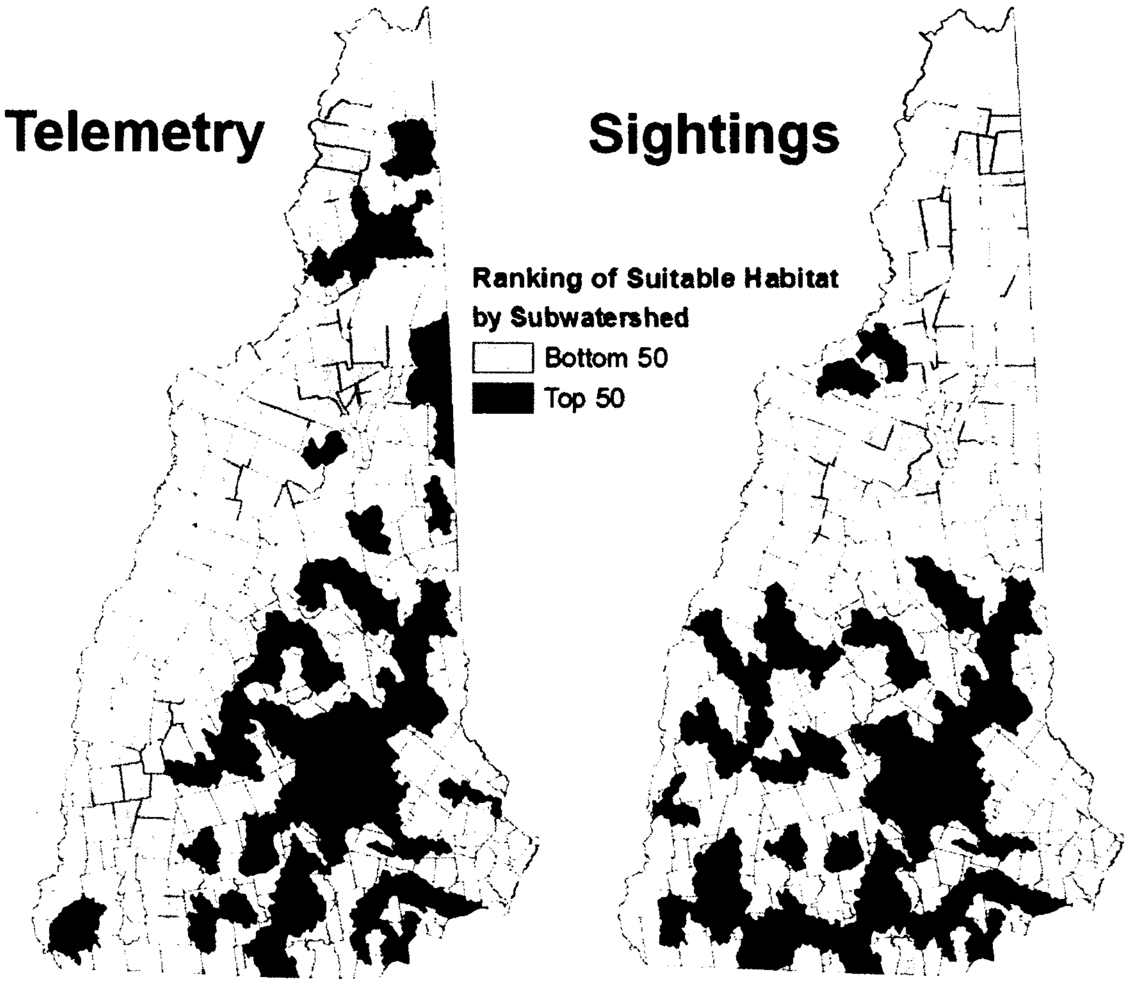

Figure 6. Maps highlighting subwatersheds with the largest and smallest amounts of suitable bobcat habitat as determined by the core-area telemetry model and sightings model. Suitable habitat is defined as map units (i.e., 90 x 90 m cells) with a RSF $\geq$ 0.5. New Hampshire consists of 327 subwatersheds.

DISCUSSION

Bobcat Habitat in New Hampshire

In New Hampshire, bobcat habitat consists of wetlands, scrublands, riparian areas, forest interiors, and areas of low elevation and low stream density. The telemetry-based models also indicated that bobcats avoided roads and human development.

The description of bobcat habitat differed between the scales of habitat selection. Home-range habitat selection consisted of selecting landscape-scale features of low elevation, low snowfall, and low stream density while also occurring near agricultural fields, wetlands, heavy development, and riparian zones (Table 3). Core-area habitat selection also indicated selection for areas of low elevation, low stream densities, and included wetland habitats, but core-area features were also located at higher distances from roads and forest edges while heavily developed areas and east aspects were avoided (Table 3). Selected habitat features at telemetry locations consisted of wetlands, scrublands, riparian zones, areas of low elevation, whereas developed lands, mixedwoods, and northwest aspects were not defined as bobcat habitat (Table 3).

It seemed that each description of habitat became more detailed as the order of selection increased. For example, home-range habitat selection (second order) indicated selection for landscape-scale habitat features of low elevation and low stream density, whereas core-area habitat addressed those landscape-scale features but included detailed features such as areas at higher distances from roads and forest edges. This trend was also observed with habitat at bobcat telemetry locations (third order) as habitat consisted of immediate features such as wetlands, scrublands, and riparian zones. This was likely an example of bobcats selecting proximate factors (factors that encourage an animal to occupy an area such as slope or elevation) at the home-range scale and ultimate factors (factors associated with survival and reproductive success such as prey availability) at the core-area and telemetry-location scales (Hilden 1965).

Although it seems odd that the telemetry models indicated bobcats would select for riparian habitat but against areas of high stream density, the cause of high stream density (i.e., topographic variation) was considerable enough to possibly cause this difference in preferences. Other studies have reported bobcat preference for low elevations (Koehler and Hornocker 1989, Fox 1990, Lovallo and Anderson 1996), but that selection may be a consequence of habitat features associated with low elevations. For example, wetlands and riparian areas often occur at low elevations. Also, high elevations in the study area generally have steeper slopes and topographic variation resulting in greater stream density. Selection for low elevation, therefore, may be a consequence of the favorable habitats that occur at low elevations.

The core-area telemetry model had the smallest ΔAIC score and 95% model confidence set of the telemetry models, was a good predictor (Table 2), and was used to compare the sightings model. However, the telemetry-location model seemed to be the most supported telemetry model when examining model covariates and how they influence extrapolation. The telemetry-location model included covariates that indicated bobcats preferred wetlands, scrublands, and riparian areas, while using lightly developed areas and northwest aspects (possibly due to low sun exposure) less than they were available (Table 3, Figure 3). Preference for low elevations has already been discussed. Bobcat preference for wetlands (or bogs) has been recorded in western Maine (Major and Sherburne 1987), western Massachusetts (Berendzen 1985), and Vermont (Donovan et al. 2011). Preference for scrublands that consist of early-successional vegetation and use of mixedwoods less than they were available was reported in Vermont (Donovan et al. 2011) whereas riparian zones were preferred by bobcats in Iowa (Tucker et al. 2008) and Illinois (Woolf et al. 2002). Koehler and Hornocker (1991) reported bobcats selected for south/southwestern facing slopes that receive high sun exposure, and therefore lower snow depths. That may indicate why the location-telemetry model indicated bobcats avoided northwestern slopes that receive low sun exposure. Extrapolation of the location-telemetry model produced a habitat-suitability map that identified those habitat features.

The core-area model identified forest interiors, areas of low stream density, and wetlands as bobcat habitat, but was strongly influenced by low elevation and placed little emphasis on the importance of the previously mentioned cover types (Table 3). Thus the core-area habitat-suitability map identified areas of low elevation and stream density and failed to recognize important cover types.

Although the home-range telemetry model was the only model to include snowfall, I feel this model was the least supported of the telemetry models when examining model covariates. That model indicated bobcats used riparian areas, areas of low elevation, low stream density, and near agricultural fields and wetlands, but the model also indicated bobcat habitat was near heavy development (Table 3). That indication was a concern because the other telemetry models and studies have reported bobcats avoiding human development. It seems the location and orientation of the minimum-convex polygon used in the sampling design for that scale of analysis was likely why the model indicated preference for areas near heavy development.

Limitations of Extrapolation from a Local Scale

Limitations on the use of data collected from a local scale are highlighted when exploring the implications of snow and roads on habitat selection. Snow depth affects bobcat mobility, physical condition, and survival (McCord 1974, Litvaitis et al. 1986), and populations in regions with deeper snow can have a male-biased sex ratio and metabolic stress (Lloyd 1990). However, my surrogate measurement for snow depth (total snowfall) occurred in only the home-range model (Table 3). The absence of this measurement in other models is likely due to the grain of the snowfall GIS layer where map units were 30-arc seconds (approximately 600 x 600 m), 6.6 times larger than most other GIS layers used in this analysis. This coarseness most likely produced little variation between used and available sampling locations. Even if snowfall had occurred in the core-area model, it is unlikely that the model could adequately identify the influence of snow on a population at the state scale because data was collected from a few individuals and in an area of moderate snowfall relative to the rest of New Hampshire. One possible option to address this limitation could be to supplement models with field sampling or expert opinion to address snow depth and perhaps similar features that are best described at a geographic range scale (Litvaitis et al. 2006).

Although the influence of roadways on habitat selection was apparent in the telemetry models, it was not as prevalent as expected as roads have a negative impact by fragmenting habitats (Noss et al. 1996) and increasing mortality due to vehicular collisions (Litvaitis et al. 1986, Anderson and Lovallo 2003). There were 3 habitat variables used in analysis that directly or indirectly represented roadways (e.g., distance to road, road density, and highway density; Table 1), but only the core-area model suggested road avoidance. Concern is raised that the models may suggest suitable habitat resides near large roadways, where in reality these areas may be uninhabitable for a bobcat. Perhaps monitored adult bobcats have learned to avoid such detrimental habitats, and therefore, their movements reflect the use of productive habitats. For example, female bobcat ID 028 had a core area that was bisected by a highway (annual daily average 5,319 vehicles per day), denned less than 200 m from that roadway, but also frequently occurred in wetland habitats. She was 10 years old at the time of initial capture (11 at recapture), so I would suggest she has learned to deal with roadways while utilizing productive habitats.

Another possibility as to why roads were not as influential as expected is the amount of traffic volume associated with these roadways. Traffic volume was not a measurement included in analysis but it is likely influential to habitat selection due to high traffic areas serving as population sinks from vehicle mortalities. The inclusion of traffic volume in model development would add an additional level to road type and could reveal strong road avoidance, specifically to those with high traffic volume.

However, if that variable was included in the telemetry models, concern would still be raised about the abilities of extrapolation because traffic volume in the study area is considered much lower than in other regions of southern New Hampshire and therefore does not adequately represent the full range of traffic volumes observed statewide. Therefore, traffic volume as a habitat feature in a model composed using data from southwest New Hampshire would likely still fail to recognize the population limiting habitat features found in other areas of the State.

In summary, bobcat habitat consisted of wetlands, scrublands, riparian areas, forest interiors, and areas of low elevation and low stream density. It seems that the models may be influenced by these potentially productive habitats (i.e., areas associated with high prey densities, loafing sites, or denning sites) more than potentially detrimental habitats (i.e., areas associated with high mortality or reduced productivity such as roadways and areas of high snow depth). This bias towards productive habitats was likely due to data coming from a few individuals at a small, relatively rural scale and resulted in the inability to identify population limiting factors like roads.

Habitat Selection from Sightings Technique

The sightings habitat model suggested animals used areas near roads, near forest edges, and areas with abundant highways (Table 3). The model also suggested selection against areas of light development. That was unexpected. However, the model revealed that although a sighting may occur in a developed area such as a backyard, the area within the buffer zone centered on the sighting consisted of less developed area than the home range buffer around it. That suggests that when sightings occur in residential areas, those areas are often small in size or in a rural location. Although different spatial scales of habitat selection were examined, the sightings model did agree with several covariates used in the telemetry models: bobcats used mixedwoods and light development less than they were available and used areas near agriculture (Table 3). However, the sightings model disagreed with the telemetry models on the use of forest edge and areas near roads and it did not recognize the important cover types. The sightings model covariates, specifically those that suggest selection for roads, are a cause for concern when determining the practicality of this technique. If the sightings model was used to manage for bobcat habitat, wetlands and riparian habitat would be ignored while the construction of roads, and inevitably forest fragmentation, would be encouraged.

The disagreement between the sightings model and telemetry models was due to the sampling design, where observations occurred near roadways or open areas (e.g., backyards, agricultural areas) and across a large scale. The use of potentially important cover types (e.g., wetlands, riparian zones) and other habitat features identified by the telemetry models could not be recognized because citizen observers were not in those habitats (Kindberg et al. 2010). Also, those features may not be as common in other areas of the State and are therefore not easily identified when examining habitat selection from sightings data collected at a statewide scale.

Habitat Distribution

Both the core area and sightings models indicated that the highest density of suitable habitat occurs in central and southeastern New Hampshire (Figure 5 and Figure 6). However, southeastern New Hampshire is generally considered to contain relatively high road and human population densities relative to the rest of the State. Although sightings indicated bobcats reside in some of these areas, they may function as population sinks as a consequence of high traffic volumes. Litvaitis and Tash (2008) developed vehicular collision models for bobcats in southeastern New Hampshire and observed high collision probabilities in much of that region. Recent road mortalities of bobcats also suggest mortalities are occurring more frequently in areas of high road density (Figure 7).

There was a moderate amount of agreement between the sightings model and the core-area model when identifying the subwatersheds with the greatest amount of suitable habitat; however, the sightings model does not agree with the telemetry model when identifying those with smallest amounts suitable habitat (Figure 6). I believe this overlap in high ranking subwatersheds occurs due to subwatersheds containing features that are suitable according to both models. For example, wetlands are an important habitat to bobcats as indicated by the core-area telemetry model, so it makes sense that 27 of the 50 top ranking subwatersheds indicated by that model were also in the top 50 subwatersheds that contained the largest amount of wetland area. Although the sightings model did not include wetland as a covariate, 31 of the 50 top ranking suitable habitat subwatersheds indicated by the sightings model were also in the top 50 subwatersheds containing the largest amount of wetland area. Thus, the sightings model identified areas of suitable habitat without consisting of the same habitat variables as the telemetry model. While this overlap may be coincidental, it seems that the sightings model may be successfully identifying areas of suitable bobcat habitat. The lack of overlap, however, between areas of low suitable habitat suggests that the sightings model is not capable of identifying areas of low suitable habitat.

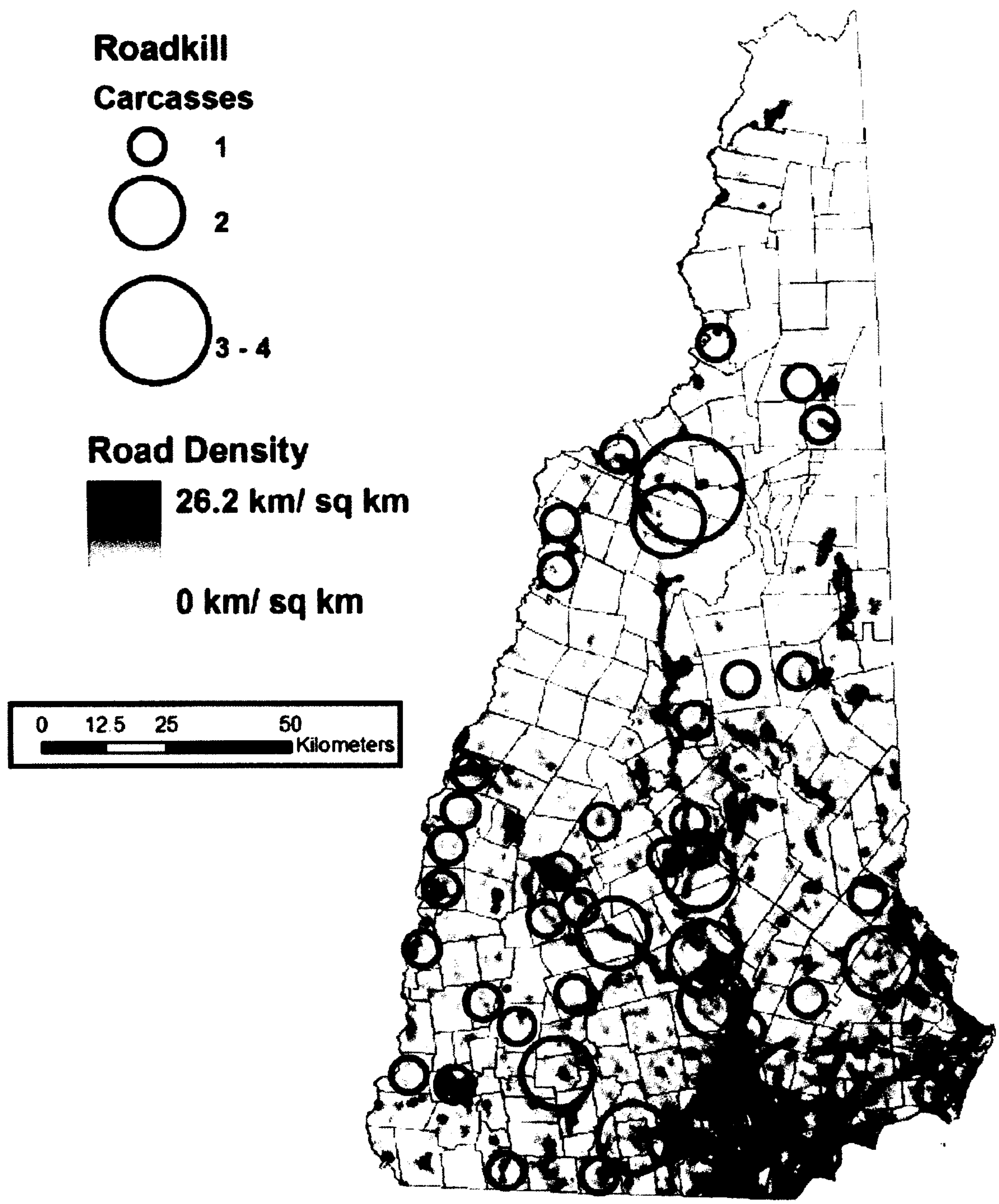

Figure 7. Number of bobcat vehicle mortalities by township from January 2007 to March 2011 (n = 57) and road density in New Hampshire. Higher numbers of mortalities per township seem to occur in areas of high road density.

Utility of Citizen Sightings

Other studies that used citizen sightings to predict bobcat distribution assessed the practicality of their techniques by comparing their estimates to independent data sources (e.g., additional sightings; Woolf et al. 2002) or previously composed models (e.g., Linde 2010). However, in my study I wanted to assess the practicality of the sightings technique by making comparisons between it and a telemetry-based approach.

When comparing habitat models, techniques can range from the simple method I used that compared the covariates present in each model and examined the level of agreement, to comparing coefficients after covariates have been standardized if the goal is to quantify the relative importance of each variable in each model (Long et al. 2009). However, I was more concerned with comparing predictions made by the sightings-based and telemetry-based habitat models, specifically the abundance and distribution of suitable habitat presented in habitat-suitability maps. One method to compare habitat-suitability maps is to examine each map and test its predictability using independent data. For example, the quantity of independent sightings that fall into areas identified as high, medium, and low suitable habitat on each map can be quantified and compared between habitat models (Sawyer et al. 2007, Rubin et al. 2009). That approach was not used because all available sightings were used for model development and no other source of bobcat data was readily available. Another method is to test for correlation between the habitat-suitability map values for each model (Cianfrani et al. 2010), but that technique does not indicate where similarities and differences occur between maps. A final approach is to conduct a qualitative comparison between the habitat-suitability maps. For example, Long et al. (2009) compared habitat suitability maps developed using two different habitat models by making a visual comparison of similarities and differences between maps. While I followed this qualitative approach, I also attempted to quantitatively compare the habitat-suitability maps by examining suitable habitat within subwatersheds, but the results were difficult to provide a clear assessment. Therefore that attempt highlighted the difficulty associated with attempting to make comparisons between model outputs and a better method to do so would be desired to better determine the practicality of the sightings technique.

The use of a website to solicit sightings worked well producing many sightings over a relatively short period of time. Observations also often contained images that greatly aided in confirming sightings were of a bobcat. Sightings brought to attention the influence of humans on winter survival as numerous sightings occurred near bird feeder or bait sites where bobcats preyed upon wild turkeys and small mammals that frequented these locations. Sightings also provide information on range expansion throughout the State. However, while the telemetry models have some limitations in identifying range-scale habitat factors such as snow and roads, the sightings model failed to recognize the habitats identified as potentially important by the telemetry models. To improve this technique, a sampling technique could be used to aid in identifying these missing features such as hunter and trapper observations, and such reports have been solicited for monitoring programs for some time (e.g., Gese 2001, Linde 2010). However, such techniques may also contain observer-bias and require considerably higher effort and finances than the technique explored here.

This technique of soliciting sightings could be a useful tool if the goal is to simply monitor the presence of an increasing carnivore population; otherwise intensive monitoring techniques such as telemetry should be used to satisfy goals to identify bobcat habitat selection, distribution, and abundance.

Utility of Telemetry Models for Identifying Suitable Habitat

The location-telemetry model appears to be the best model for identifying habitat features, but the core-area model also helps highlight forest interiors as being important habitat. Following these models' suggestions, managing for bobcat habitat includes managing wetlands and early-successional shrub/scrub while also trying to preserve forest interiors.

The habitat-suitability map composed using the location- model should be used for identifying and managing suitable bobcat habitat in the State (Figure 3). However, concern should be raised about what is indicated in Wildlife Management Units (WMU) K, L, and M. WMUs K, L, and M contain the highest human and road densities in the State (Figure 7), yet the model suggested high amounts of suitable habitat (Figure 8). Thus, the model may be overestimating the amount of suitable habitat in those WMUs.

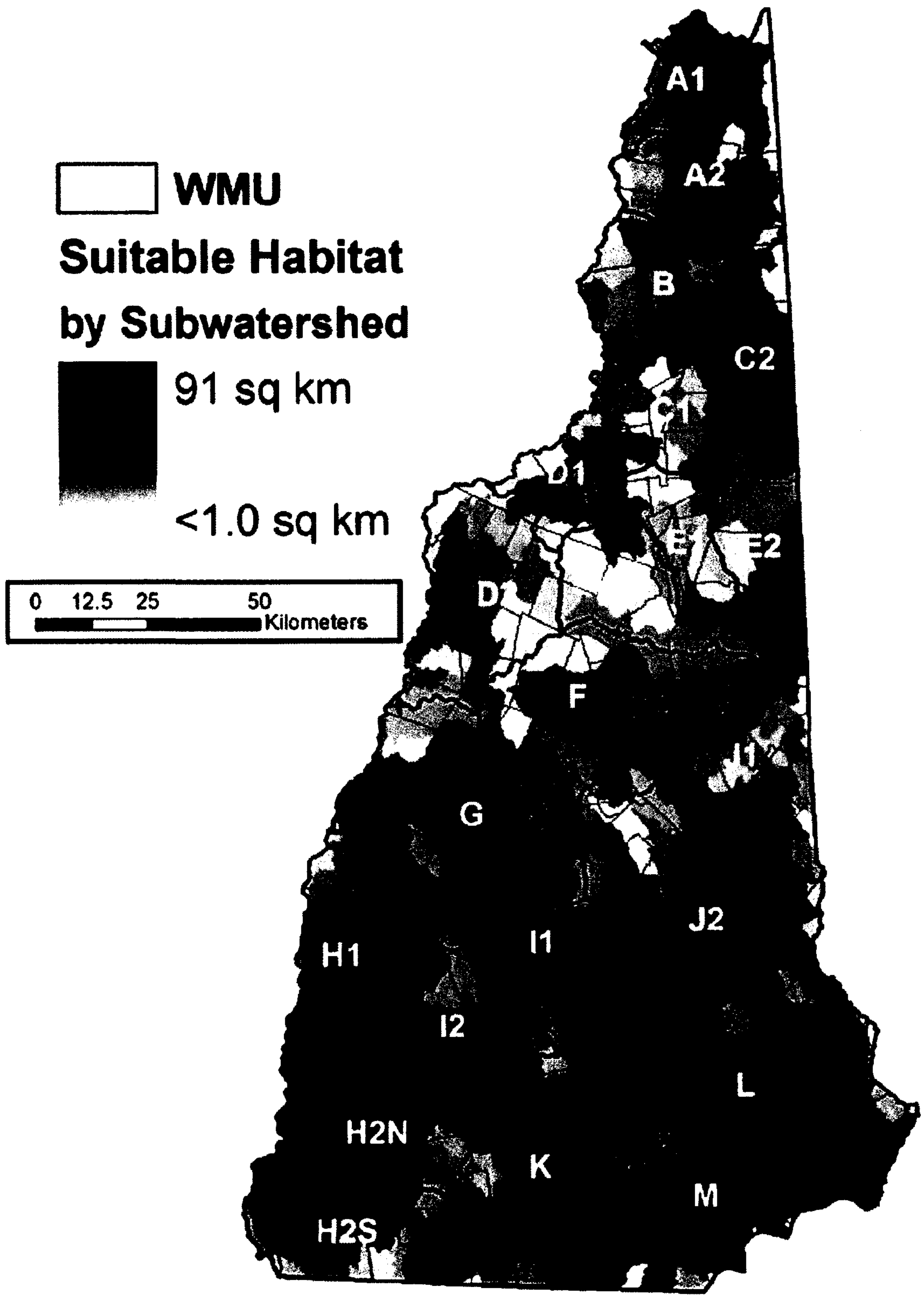

Figure 8. An illustration of the relationship between the amount of suitable habitat by subwatershed using the location-telemetry model and New Hampshire Fish and Game Wildlife Management Units (WMU). The location-telemetry model was developed using telemetry data from bobcats in southwest New Hampshire from November 2008 to December 2010. Suitable habitat is defined as map units (i.e., 90 x 90 m cells) with a RSF ≥ 0.5.

CHAPTER III

Abundance Estimates of Bobcats in New Hampshire

Little is known about the current abundance and distribution of bobcats in New Hampshire. Bobcats have been protected in New Hampshire since 1989, and populations seem to be increasing (Litvaitis et al. 2006, Roberts and Crimmins 2010). Current information on bobcat distribution in the State is limited to incidental sightings and captures plus vehicle-related mortalities (Litvaitis et al. 2006). Due to this lack of information, bobcat habitat evaluations from Chapter II were used to develop statewide abundance estimates.

I used 2 techniques to estimate potential bobcat abundances based on approaches used by Roloff and Haufler (1997), Lovallo (1999), and Nielsen and Woolf (2002) that included some aspect of habitat-area requirements. To compare my estimates with surrounding states, I contacted furbearer biologists in the 5 other New England states inquiring about the status of their bobcat populations, population size, and how abundance was determined.

Technique 1: Statewide Carrying Capacity

This technique first consisted of measuring the amount of suitable habitat (RSF $\geq$ 0.5) in the State as defined by the location-telemetry model. I then quantified the amount of suitable habitat within the home ranges of monitored bobcats (9M, 1F) and assumed the average amount of habitat observed in these home ranges was the minimum threshold of habitat required for a home range. Finally, I divided the statewide amount of suitable habitat by this average amount of suitable habitat observed in a home range to produce a number of potential home ranges. This technique assumes that home ranges can vary in size. Because only 1 female home range was measured, that value of suitable habitat was assumed to be the minimum threshold necessary for a female home range.

This technique indicated that there are 329 male and 623 female potential home ranges of resident adult bobcats (sum= 952) in New Hampshire (Table 5), a statewide density of 0.04 adult bobcats per square kilometer.

Table 4. The amount of suitable habitat found in the home ranges of 10 monitored bobcats. Bobcat ear tag number (ID), sex, home range size, amount of suitable habitat within home range, and percent home range comprised by suitable habitat is presented. The average value (*) was assumed to be the amount of suitable habitat required for a home range to be suitable for a bobcat.

ID	Sex	Home Range Size (km^2)	Amount of Suitable Habitat (km^2)	Percent of Home Range
26	M	72.59	36.68	51%
27	M	126.59	43.16	34%
29	M	54.37	22.19	41%
30	M	103.05	30.93	30%
31	M	61.57	21.08	34%
32	M	56.41	20.52	36%
33	M	59.83	20.59	34%
34	M	80.18	34.99	44%
39	M	28.69	10.18	35%
.	Male Mean	71.48	26.70*	38%
28	F	29.69	14.11*	48%

Table 5. Values for the calculation of potential home ranges using Statewide Carrying Capacity technique that divided the amount of statewide suitable habitat by the mean amount of suitable habitat within home ranges of monitored bobcats that served as a minimum threshold for suitable habitat. The amount of statewide suitable habitat, minimum amount of suitable habitat per home range, and number of potential home ranges are presented.

State Suitable Habitat (km^2)	Sex	Minimum Threshold of Home Range Suitable Habitat (km^2)	Potential Home Ranges Statewide
8,794	Male	26.7	329
8,794	Female	14.1	623
			Total: 952

Technique 2: Home Range Carrying Capacity

This technique was similar to the statewide carrying capacity technique in that I used the location-telemetry model to identify suitable habitat statewide, quantified suitable habitat within bobcat home ranges to determine the average amount, and used that mean value to determine the minimum amount of suitable habitat in a home range. However, I also quantified the amount of overlap of composite home ranges to determine the mean amount of overlap between ranges. In 9 accounts of male home range overlap, the mean amount of overlap was 10.4 km^2 (32% male home range; Min = 0.98 km^2, Max = 29.80 km^2). As there was data for only 1 female and female home ranges are typically considered to be exclusive of other females (Anderson and Lovallo 2003), it was assumed that there was 0% overlap between female home ranges.

In GIS, two grids were created: one grid was composed of grid cells equal in size to the mean male home range after accounting for mean overlap (63.6 km^2, exclusive home range) and the other consisted of grid cells equal in size to the home range of female bobcat ID #028 (29.69 km^2, Table 4). These grids were combined with the suitable habitat map of New Hampshire and the amount of suitable habitat was quantified within each cell (Figure 9). Because grid cells were a fixed size, this estimate assumed that all exclusive home ranges for each sex were the same statewide.

Although there was only 1 female home range estimated in this study, I did have location data for another female bobcat in the study area. These locations (n = 5) were from captures and ground and aerial telemetry from Mar-2010 to Mar-2011 and although they were not used to calculate a home range, they provided a good indication of where her home range likely occurred. Therefore, when the female minimum suitable habitat value from the Statewide Carrying Capacity (14.11 km^2, Table 5) failed to recognize the grid cell where the other female's home range likely occurred as a potential home range, I chose to use that grid cell's value (10.7 km^2) as the minimum threshold of suitable habitat required for a potential female home range. Grid cells meeting this minimum requirement numbered 339 (Table 6). For the male grid, cells containing a minimum of 26.7 km^2 of suitable habitat (Table 5) were considered potential home ranges and numbered 126 (Table 6). Thus this technique estimated 465 potential home ranges for resident adult bobcats in New Hampshire, a statewide density of 0.02 adult bobcats per square kilometer.

Table 6. The values used to calculate the number of potential statewide home ranges using the Home Range Carrying Capacity technique where two grids were used: one containing grid cells equal to the male mean home range adjusted for mean overlap (i.e., male exclusive home range) and the other contained grid cells equal to the home range of female bobcat ID #028. These grids were combined with a suitable habitat map of New Hampshire and the amount of suitable habitat within each cell was quantified. The values for the minimum threshold of suitable habitat came from the mean amount of suitable habitat within known male home ranges and the general area of a monitored female home range. Cells containing the minimum amount of suitable habitat were determined to be potential home ranges.

Sex	Minimum Threshold of Home Range Suitable Habitat (km^2)	Grid Cell/ Exclusive Home Range Size (km^2)	Number of Cells in Grid Covering New Hampshire	Potential Home Ranges Statewide
Male	26.7	63.6	423	126
Female	10.7	29.7	999	339
				Total: 465

Examining Figure 9 that illustrates an intermediate step in the Home Range Carrying Capacity technique, one can speculate that grid cells with high amounts of suitable habitat could possibly support more than one individual. Another consideration was that grid cells or clusters of cells with low amounts of suitable habitat would require bobcats in that area to have larger home ranges to encompass the necessary amount of suitable habitat.

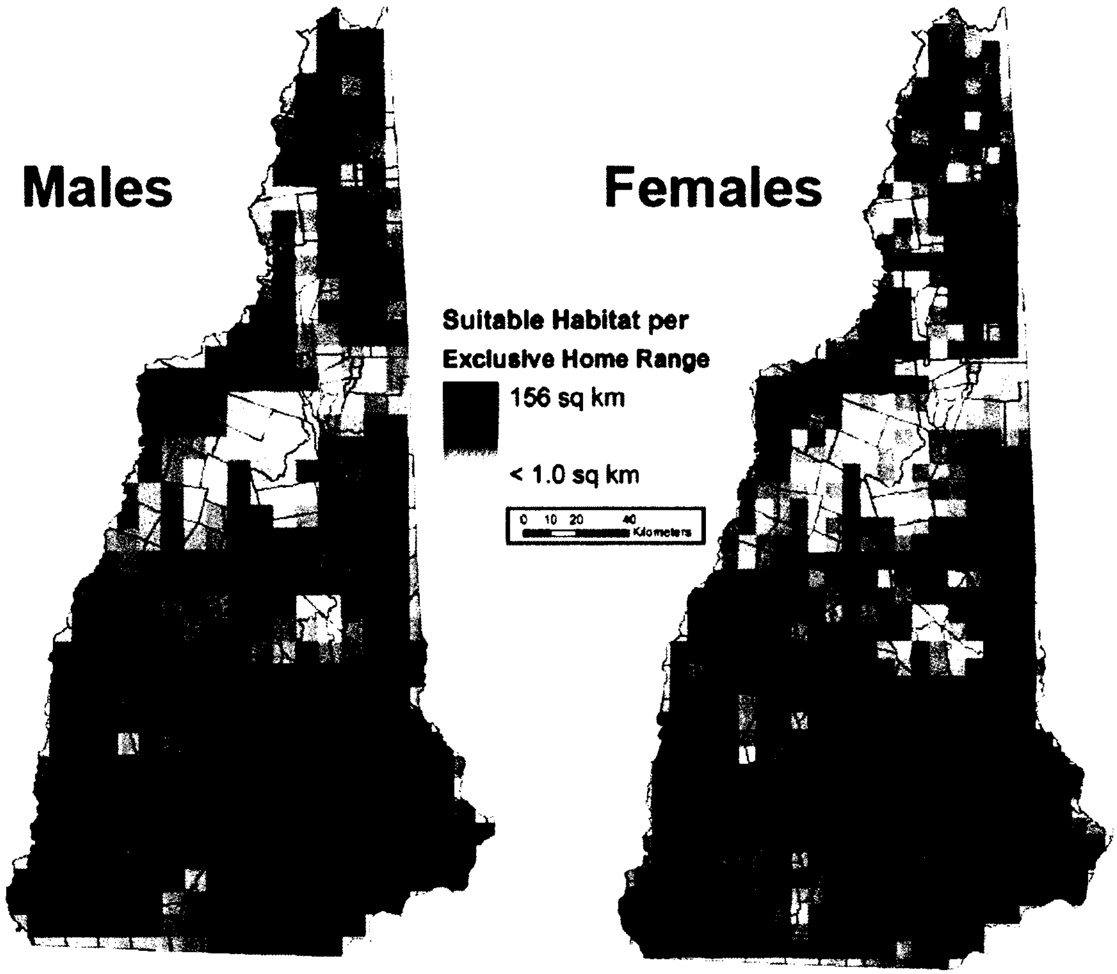

Figure 9. Amount of suitable habitat within male and female exclusive home ranges in New Hampshire as indicated by the location-telemetry model. Home ranges and the location-telemetry model were developed using telemetry data from bobcats in southwest New Hampshire from November 2009 to December 2010. Exclusive home ranges are mean home ranges accounting for mean overlap. This map is an intermediate step in estimating Technique 2: Home range carrying capacity where home range was determined to be occupied if the amount of suitable habitat within it was above a mean threshold determined by examining the amount of suitable habitat within known or estimated home ranges. Occupied exclusive home ranges contained 26.7 km^2 suitable habitat for males and 10.7 km^2 for females, and yielded estimates of 126 males and 339 females.

Bobcats in New England States

Of the 5 other New England states, 3 have an open harvest but all states have bobcats and their populations appear to be increasing. All states record roadkills and most record other information such as incidental captures or reported sightings. Maine, Massachusetts, and Vermont monitor harvests and calculate indexes such as trapper/harvester success (e.g., the number of trappers that harvested a bobcat divided by the number of trappers who harvested other terrestrial furbearers) but harvest data is not used to produce an estimate of potential abundance. Two states (Massachusetts and Vermont) have estimates of potential home ranges that were derived using information on suitable habitat and area requirements and included a population component to address yearlings. Massachusetts derived habitat information from bobcat literature to construct a density estimate that follows the Statewide Carrying Capacity technique. In Vermont, Freeman (2010) used an estimate similar to the Statewide Carrying Capacity technique but efforts are currently underway to produce a carrying capacity estimate that is similar to the Home Range Carrying Capacity technique. Connecticut, Maine, and Rhode Island have no current estimates of bobcat populations or potential home ranges.

Recommendations

It is not completely clear as to which potential home range technique should be used as both techniques have assumptions and limitations. The statewide carrying capacity technique that consisted of dividing the amount of suitable habitat within the State by home range habitat requirements, allowed for home ranges to vary in size and a similar technique was used in Massachusetts and Vermont. However, this technique ignores the arrangement of habitat that, in some cases, may be scattered or separated by great distances. That technique also has a value that is nearly twice the estimate of the home range carrying capacity technique, but both values seem low yet plausible considering New Hampshire's size and landscape. The home range carrying capacity technique included a spatial component that addressed scattered or separated habitat, but assumed home ranges were the same size throughout New Hampshire and therein lay one of the concerns regarding extrapolation of data collected at a local scale.

Table 7. The current status of bobcats in the 6 New England states according to information obtained from wildlife biologists. Information on the status of a bobcat harvest, current data collected and available to wildlife managers, abundance estimates or indexes used to monitor population status, and data sources used obtain abundance estimate or index are presented.

State	Harvest Status	Current Available Data	Abundance Estimate or Index Used to Monitor Population	Estimate Source
Connecticut	Closed	Sightings, Incidental Captures and Roadkills	NA	NA
New Hampshire	Closed	Sightings, Incidental Take, Roadkills and Monitored Individuals	465-952 Potential Individuals	Habitat area requirements from monitored bobcats
Maine	Open	Harvest and Roadkills	Harvester Success	Trapper Effort Data
Massachusetts	Open	Harvest, Sightings and Roadkills	Harvester Success and 1,200 Potential Individuals	Density Estimates Using Literature Derived Habitat Requirements
Rhode Island	Closed	Sightings and Roadkills	NA	NA
Vermont	Open	Harvest, Sightings, Incidental Take, Roadkills, and Monitored Individuals	Harvester Success and 2,500-3,500 Potential Individuals*	Habitat area requirements from monitored bobcats

* = Old estimate. New estimate currently being developed.

Both techniques quantified the average amount of suitable habitat within each male home range and the home range carrying capacity technique also included average home range overlap to estimate a mean male exclusive home range. While those techniques served as the most logical approach to estimate statewide abundance, if the objective were to estimate a maximum carrying capacity for bobcats in New Hampshire, measures of the minimum amount of suitable habitat within a home range and maximum overlap observed between home ranges could be used. For example, I used the minimum amount of suitable habitat in a home range (10.18 km^2; Table 4) and the maximum home range overlap (32%, 29.8 km^2) to develop maximum abundance estimates using the Statewide and home range carrying capacity techniques (Table 8). These maximum estimates (864 males for statewide carrying capacity, 431 males for home range carrying capacity) are considerably higher than the estimates using mean suitable habitat per home range and mean home range overlap (329 males for statewide carrying capacity, 126 males for home range carrying capacity; Table 8) but illustrate how much estimates could change by assuming minimal habitat-area requirements.

New data from monitored bobcats in southeast New Hampshire could help determine if or how home range size varies from one side of the State to the other. Analysis on this data has not yet occurred, however initial observations suggest home ranges for these southeastern individuals are much smaller than individuals in the southwest. If this is true, these smaller area requirements may indicate I underestimated statewide abundance. New data would also be useful when developing potential home range estimates for females as data for only 1 female was available for this analysis. Current monitored bobcats include 4 females and could greatly help support current or develop new estimates.

Table 8. Comparison of the calculation of the expected and maximum potential male home ranges using the statewide carrying capacity technique that divided the amount of statewide suitable habitat by a threshold of home range suitable habitat and the home range carrying capacity technique that quantified the amount of suitable habitat within exclusive home range sized grid cells and determined cells to be occupied if the quantity met a suitable habitat threshold. The expected potential home range estimate used mean measurements of suitable habitat within male home ranges and mean home range overlap, whereas the maximum potential home range estimate used the minimum amount of male home range suitable habitat and maximum home range overlap.

Abundance Estimate Technique	Source for Threshold of Home Range Suitable Habitat	Source for Home Range Overlap	Potential Home Ranges Statewide
Statewide Carrying Capacity	Mean amount of suitable habitat within male home ranges	NA	329
	Minimum amount of suitable habitat within a male home range	NA	864
Home Range Carrying Capacity	Mean amount of suitable habitat within male home ranges	Mean overlap of male home ranges	126
	Minimum amount of suitable habitat within a male home range	Maximum overlap observed between male home ranges	431

Abundance estimates were of resident adult bobcats, but if managers desired to develop a population estimate that included juveniles, life tables developed from New Hampshire carcasses (if available) or presented in the literature could be combined with the resident adult estimates. For example, Rolley (1985) constructed life tables using data from harvested and monitored bobcats in Oklahoma that reported adult female pregnancy rate, mean litter size, juvenile survival, and population age structure. Similar information could be applied to adult female estimates to determine the number of offspring and their survival rates for each female, essentially producing a juvenile abundance estimate.

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APPENDICES

APPENDIX A

UNIVERSITY OF NEW HAMPSHIRE INSTITUTIONAL ANIMAL CARE AND USE COMMITTEE LETTER OF APPROVAL

University *of* New Hampshire

Research Integrity Services, Office of Sponsored Research
Service Building, 51 College Road, Durham, NH 03824-3585
Fax: 603-862-3564

05-Feb-2009

Litvaitis, John A
Natural Resources & The Environment, James Hall
Durham, NH 03824

IACUC #: 081201
Project: Population Ecology of Bobcats in New Hampshire
Category: D
Approval Date: 17-Dec-2008

The Institutional Animal Care and Use Committee (IACUC) reviewed and approved the protocol submitted for this study under Category D on Page 5 of the Application for Review of Vertebrate Animal Use in Research or Instruction - *the research involves chronic maintenance of animals with a disease/functional deficit and/or procedures potentially inducing moderate pain, discomfort or distress which will be treated with appropriate anesthetics/analgesics.* The IACUC made the following comment(s) on this protocol:

1. The subcommittee requests that the investigator start with box traps only (no leg traps) to see if this capture method works. If it does not, or will not given the environmental conditions, the investigator may use leg traps. If the investigator uses leg traps, he will need to develop a written "justification of use" for the leg traps and send it to Dean Elder for the IACUC's and USDA's records.
2. The protocol will be categorized as USDA pain and distress category D. If in the course of the study, an E "event" occurs, (e.g. a broken leg, an animal needs to be euthanized) UNH will need to report this to the USDA in its annual report as such (see #3).
3. The subcommittee requests that the investigator incorporate a chart (similar to or as previously presented) for determination of injury and subsequent disposition of animals (i.e., no pain relief needed/pain medication administered, [e.g. butorphanol/euthanization]). The investigator will need to report to Dean Elder the findings/disposition of all animals involved in the study for the period 10/1/08-9/30/09 in the first week of October 2009 for UNH's annual USDA report.

Approval is granted for a period of three years from the approval date above. Continued approval throughout the three year period is contingent upon completion of annual reports on the use of animals. At the end of the three year approval period you may submit a new application and request for extension to continue this project. Requests for extension must be filed prior to the expiration of the original approval.

(Appendix A cont'd)

Please Note:

1. All cage, pen, or other animal identification records must include your IACUC # listed above.
2. Use of animals in research and instruction is approved contingent upon participation in the UNH Occupational Health Program for persons handling animals. Participation is mandatory for all principal investigators and their affiliated personnel, employees of the University and students alike. A Medical History Questionnaire accompanies this approval; please copy and distribute to all listed project staff who have not completed this form already. Completed questionnaires should be sent to Dr. Gladi Porsche, UNH Health Services.

If you have any questions, please contact either Dean Elder at 862-4629 or Julie Simpson at 862-2003.

For the IACUC,

Jessica Bolker

Jessica A. Bolker, Ph.D.
Chair

cc: File

APPENDIX B

COMPOSITE AND SEASONAL HOME RANGE AND CORE AREA ESTIMATES

Appendix B: Table 1. Home range (95 UD) and core area (50 UD) size estimates by season for 11 collared bobcats in southwest New Hampshire. Composite is all telemetry locations, Winter 2009 is 1 Nov 2009 – 31 Mar 2010, Spring 2010 is 1 Apr – 15 June 2010, Summer 2010 is 16 June – 31 Oct 2010. Home ranges and core areas were calculated using fixed kernel density estimators if the number of locations at that temporal scale was ≥ 30.

			Winter 2009		Spring 2010		Summer 2010		Winter 2010		Composite	
Bobcat ID	**Sex**	**UD**	**Area (km^2)**	**Locations**	**Area (km^2)**	**Locations**	**Area (km^2)**	**Locations**	**Area (km^2)**	**Locations**	**Area (km^2)**	**Locations**
26	**Male**	**95**	48.79	410.00	66.76	258.00	99.12	192.00	.	.	72.59	860.00
		50	3.48		2.24		4.11		.		5.26	
27	**Male**	**95**	76.20	187.00	230.14	283.00	34.29	378.00	.	.	126.59	848.00
		50	10.59		13.65		2.92		.		5.72	
28	**Female**	**95**	24.68	258.00	31.34	175.00	.	.	.	.	29.69	433.00
		50	1.54		2.17		.		.		2.47	
29	**Male**	**95**	56.69	60.00	48.24	101.00	49.22	72.00	.	.	54.37	233.00
		50	9.45		8.46		15.07		.		14.03	
30	**Male**	**95**	59.04	164.00	81.51	251.00	116.71	290.00	.	.	103.05	705.00
		50	6.99		6.70		17.66		.		9.79	
31	**Male**	**95**	.	.	.	.	61.57	94.00	.	.	61.57	94.00
		50	.		.		10.45		.		10.45	
32	**Male**	**95**	45.39	34.00	87.16	81.00	37.62	90.00	.	.	56.41	205.00
		50	4.57		17.61		2.59		.		2.33	
33	**Male**	**95**	54.99	31.00	45.35	34.00	.	*24.00*	.	.	59.83	89.00
		50	8.11		4.69		.		.		9.98	
34	**Male**	**95**	53.50	43.00	81.30	102.00	90.50	198.00	83.02	73.00	80.18	416.00
		50	7.21		11.33		26.37		10.19		8.59	
39	**Male**	**95**	.	*19.00*	23.70	111.00	36.70	185.00	39.75	66.00	28.69	381.00
		50	.		2.03		4.28		3.87		1.85	
40	**Male**	**95**	45.44	37.00	180.43	134.00	214.90	148.00	.	.	292.07	319.00
		50	3.29		17.88		27.95		.		47.80	
Mean	**.**	**95**	51.64	136	87.59	153	82.29	183	61.39	69.5	87.73	416.64
		50	6.14		8.68		12.38		7.03		10.75	

APPENDIX C

COMPOSITE AND SEASONAL HABITAT SELECTION MODEL COVARIATES

Taking into account bobcat behavior, annual climate change in New Hampshire, and data availability, bobcat GPS data was divided into three seasons: Winter 2009, 1-Nov-09 through 31-Mar-10; Spring, 1-Apr-10 through 15-June-10; and Summer, 16-June-10 through 31-Oct-10. For a composite temporal scale, all locations across all seasons were used, thus 4 temporal scales of habitat selection were analyzed. For each scale, home ranges and core areas were calculated using fixed kernel density estimators and a Resource Selection Function using a used vs. availability design was used to identify habitat selection. The following tables display the results of RSFs conducted at these temporal scales.

Appendix C: Table 1. Model covariates and values across all seasons for the GPS location telemetry model. Composite is all locations, Winter 2009 is 1 Nov 2009 – 31 Mar 2010, Spring 2010 is 1 Apr – 15 June 2010, Summer 2010 is 16 June – 31 Oct 2010.

	Composite			**Winter 2009**			**Spring 2010**			**Summer 2010**		
Variable	**β**	**SE**	***P***	**β**	**SE**	***P***	**β**	**SE**	***P***	**β**	**SE**	***P***
Intercept	0.0815	0.0835	0.329	-0.2287	0.1798	0.203	0.1078	0.0542	0.047	0.4548	0.0858	<0.001
Wetland	0.9976	0.0843	<0.001	0.8873	0.1423	<0.001	0.9638	0.1386	<0.001	0.9866	0.1515	<0.001
Mixedwood	-0.0791	0.0480	0.099							-0.1884	0.7570	0.013
Distance to Stream	-3.22E-06	1.28E-06	0.012							-0.0010	0.0002	<0.001
Elevation	-1.39E-06	2.65E-06	0.601									
Aspect = Northwest	-0.1919	0.0679	0.005									
Scrubland	0.5345	0.1837	0.004									
Light Development	-0.2276	0.1022	0.026				-0.4615	0.1849	0.013			
Distance to Scrubland				0.0003	0.0001	<0.001						
Open Water				-0.9453	0.4249	0.026	-0.7435	0.2852	0.009			
Stream Density				-0.1819	0.0962	0.059						
Ruggedness				1.4830	0.4105	<0.001				-0.7921	0.4685	0.091
Highway Density							-0.3152	0.1009	0.002			
Softwood							-0.1049	0.0818	0.200			
Aspect = North							-0.2651	0.1272	0.037			
Distance to Agriculture										-0.0032	0.0001	0.002
Distance to Wetland										-0.0001	0.0001	0.174

Appendix C: Table 2. Model covariates and values across all seasons for the core area telemetry model. Composite is all locations, Winter 2009 is 1 Nov 2009 – 31 Mar 2010, Spring 2010 is 1 Apr – 15 June 2010, Summer 2010 is 16 June – 31 Oct 2010.

	Composite			Winter 2009			Spring 2010			Summer 2010		
Variable	**β**	**SE**	***P***	**β**	**SE**	***P***	**β**	**SE**	***P***	**β**	**SE**	***P***
Intercept	1.3070	0.2653	<0.001	0.0753	0.1068	0.481	3.3470	0.3764	<0.001	1.2016	0.2040	<0.001
Elevation	-3.56E-05	5.91E-06	<0.001				-0.0055	0.0008	<0.001	-0.0022	0.0007	0.002
Distance to Edge	4.66E-06	2.37E-06	0.050	0.0004	0.0002	0.067						
Heavy Development	-14.78	539.8	0.978	-2.1100	1.0810	0.051						
Stream Density	-3.56E-05	9.75E-06	<0.001				-0.3993	0.1131	<0.001			
Wetland	0.5143	0.1968	0.009				0.3693	0.1970	0.061			
Distance to Road	4.84E-06	2.00E-06	0.016									
East Aspect	0.1811	0.1158	0.118									
Southeast Aspect				0.3215	0.1434	0.025						
Distance to Agriculture				0.0004	0.0002	0.010						
Distance to River							0.0002	9.19E-05	0.014			
Distance to Scrubland										-0.0005	0.0001	<0.001
Distance to Water				-0.0005	0.0001	<0.001						
Distance to Wetland										-0.0003	0.0002	0.065
Road Density							-4.84E-05	8.40E-06	<0.001			
Highway Density							-1.6940	0.1813	<0.001			
Open Water							-0.8803	0.3489	0.012			

Appendix C: Table 3. Model covariates and values across all seasons for the home range telemetry model. Composite is all locations, Winter 2009 is 1 Nov 2009 – 31 Mar 2010, Spring 2010 is 1 Apr – 15 June 2010, Summer 2010 is 16 June – 31 Oct 2010.

	Composite			Winter 2009			Spring 2010			Summer 2010		
Variable	**β**	**SE**	***P***	**β**	**SE**	***P***	**β**	**SE**	***P***	**β**	**SE**	***P***
Intercept	2.9170	6.9430	<0.001	3.3760	0.7951	<0.001	0.3787	0.1237	0.002	0.8322	0.2174	<0.001
Distance to Agriculture	-1.30E-06	1.20E-06	0.279									
Distance to Heavy Development	-4.27E-07	2.96E-07	0.150	-2.05E-06	3.91E-07	<0.001	-1.43E-06	2.68E-07	<0.001	-7.92E-07	3.17E-07	0.012
Distance to River	-1.12E-06	8.06E-07	0.165									
Distance to Wetland	-2.90E-06	1.38E-06	0.035	-6.61E-09	1.72E-06	<0.001						
Elevation	-1.42E-05	6.66E-06	0.033	-3.55E-05	7.43E-06	<0.001				-2.21E-05	5.90E-06	<0.001
Snowfall	-2.30E-05	1.19E-05	0.053	7.28E-06	1.40E-05	0.604						
Stream Density	-4.63E-05	1.02E-05	<0.001	-4.46E-05	1.11E-05	<0.001						
Road Density				-7.28E-05	8.28E-06	<0.001						
South Aspect				-0.2414	0.1586	0.128052						
Southeast Aspect							-0.3617	0.1414	0.011	0.3222	0.1493	0.031
Highway Density							1.52E-05	1.38E-05	0.272	2.64E-05	1.53E-05	0.086
Agriculture							0.2478	0.1728	0.152			
Light Development										0.1647	0.151	0.276
Northwest Aspect										-0.3449	0.1535	0.025

APPENDIX D

CORRELATION COEFFICIENTS FROM MODEL DEVELOPMENT

Prior to model development, a Spearman rank correlation was used to identify collinearity between continuous variables. If $r \geq 0.70$, the more biologically meaningful habitat variable was retained (Saher and Schmiegelow 2005). The following tables are the correlation coefficients for each habitat model.

Appendix D: Table 1. Correlation coefficients for GPS location-telemetry model.

	slope	elev	vrm	snow	stmdens	rdensit	dtwater	dtstream	dtscrub	dtroad	dtriver	dtltdev	dthwy	dthwydev	dtedge	dtdisturb	dtag	dtwetland	roadens
slope	1.000																		
elev	0.211	1.000																	
vrm	1.000	0.211	1.000																
snow	-0.222	0.291	-0.222	1.000															
stmdens	-0.012	-0.351	-0.012	-0.361	1.000														
rdensit	-0.121	-0.439	-0.121	-0.116	0.225	1.000													
dtwater	0.194	-0.048	0.194	-0.241	0.104	0.093	1.000												
dtstream	0.237	0.226	0.237	0.041	-0.290	-0.101	0.018	1.000											
dtscrub	0.163	0.369	0.163	0.105	-0.140	-0.251	-0.149	0.074	1.000										
dtroad	0.175	0.129	0.175	-0.072	-0.023	-0.212	0.058	0.100	0.044	1.000									
dtriver	0.175	0.590	0.175	0.098	-0.449	-0.516	-0.001	0.256	0.296	0.101	1.000								
dtltdev	0.206	0.259	0.206	-0.016	-0.076	-0.337	-0.001	0.117	0.086	0.777	0.203	1.000							
dthwy	0.106	0.454	0.106	0.123	-0.234	-0.891	-0.120	0.107	0.249	0.305	0.530	0.416	1.000						
dthwydev	0.149	0.436	0.149	0.045	0.079	-0.338	0.109	-0.019	0.188	0.132	0.245	0.220	0.306	1.000					
dtedge	0.092	0.142	0.092	-0.020	-0.029	-0.174	-0.035	0.069	0.192	0.604	0.095	0.681	0.239	0.144	1.000				
dtdisturb	0.049	0.250	0.049	0.173	0.100	-0.155	0.036	-0.045	0.058	0.049	0.130	0.124	0.170	0.292	0.068	1.000			
dtag	0.233	0.367	0.233	0.107	-0.214	-0.259	-0.031	0.157	0.281	0.361	0.262	0.441	0.262	0.216	0.558	0.067	1.000		
dtwetland	0.494	0.328	0.494	-0.234	-0.045	-0.210	0.257	0.258	0.170	0.074	0.309	0.135	0.188	0.129	-0.011	0.098	0.151	1.000	
roadens	-0.217	-0.161	-0.217	0.175	0.007	0.430	-0.176	-0.055	-0.043	-0.492	-0.202	-0.455	-0.369	-0.375	-0.353	-0.083	-0.299	-0.131	1.000

Appendix D: Table 2. Correlation coefficients for core-area telemetry model.

	slope	elev	vrm	snow	stmdens	rdensit	roadens	dtwater	dtstream	dtscrub	dtroad	dtriver	dtltdev	dthwy	dthwydev	dtedge	dtdisturb	dtag	dtwetland
slope	1.000																		
elev	0.284	1.000																	
vrm	1.000	0.284	1.000																
snow	-0.211	0.262	-0.211	1.000															
stmdens	-0.020	-0.217	-0.020	-0.325	1.000														
rdensit	-0.191	-0.510	-0.191	-0.063	0.237	1.000													
roadens	-0.275	-0.285	-0.275	0.186	-0.042	0.469	1.000												
dtwater	0.170	-0.012	0.170	-0.191	0.189	0.078	-0.151	1.000											
dtstream	0.181	0.166	0.181	0.089	-0.352	-0.113	-0.023	-0.039	1.000										
dtscrub	0.121	0.359	0.121	0.087	-0.120	-0.228	-0.085	-0.136	0.052	1.000									
dtroad	0.211	0.152	0.211	-0.120	0.023	-0.239	-0.535	0.084	0.066	0.060	1.000								
dtriver	0.179	0.557	0.179	0.079	-0.423	-0.446	-0.208	-0.022	0.227	0.261	0.095	1.000							
dtltdev	0.267	0.347	0.267	-0.027	-0.047	-0.383	-0.498	-0.034	0.110	0.133	0.773	0.206	1.000						
dthwy	0.173	0.481	0.173	0.061	-0.227	-0.894	-0.407	-0.080	0.112	0.216	0.301	0.437	0.420	1.000					
dthwydev	0.206	0.567	0.206	0.056	0.125	-0.413	-0.382	0.084	-0.045	0.275	0.151	0.245	0.302	0.362	1.000				
dtedge	0.134	0.219	0.134	-0.017	-0.007	-0.219	-0.374	-0.067	0.085	0.232	0.609	0.084	0.741	0.256	0.245	1.000			
dtdisturb	0.043	0.335	0.043	0.283	0.172	-0.143	-0.050	-0.074	-0.047	0.196	0.050	0.084	0.176	0.146	0.396	0.122	1.000		
dtag	0.258	0.382	0.258	0.096	-0.198	-0.326	-0.265	-0.035	0.147	0.306	0.296	0.218	0.430	0.294	0.285	0.560	0.082	1.000	
dtwetland	0.462	0.342	0.462	-0.266	-0.048	-0.289	-0.173	0.203	0.175	0.107	0.095	0.307	0.168	0.275	0.150	0.044	0.022	0.207	1.000

Appendix D: Table 3. Correlation coefficients for home-range telemetry model.

	roadens	slope	dthvydev	dtedge	dtdisturb	dtag	elev	vrm	dtwetland	dtroad	dtscrub	rdensit	dtwater	snow	stmdens	dtriver	dtstream	dtltdev	dthwy
roadens	1.000																		
slope	-0.244	1.000																	
dthvydev	-0.424	0.163	1.000																
dtedge	-0.376	0.147	0.191	1.000															
dtdisturb	-0.249	0.089	0.397	0.123	1.000														
dtag	-0.372	0.198	0.334	0.568	0.227	1.000													
elev	-0.382	0.205	0.641	0.212	0.337	0.366	1.000												
vrm	-0.231	0.872	0.150	0.149	0.087	0.191	0.201	1.000											
dtwetland	-0.126	0.370	0.114	0.069	0.062	0.124	0.223	0.383	1.000										
dtroad	-0.535	0.190	0.173	0.534	0.134	0.311	0.229	0.191	0.070	1.000									
dtscrub	-0.147	0.160	0.209	0.213	0.125	0.231	0.319	0.168	0.192	0.109	1.000								
rdensit	0.503	-0.117	-0.482	-0.268	-0.210	-0.316	-0.448	-0.110	-0.125	-0.209	-0.209	1.000							
dtwater	-0.128	0.210	0.023	0.019	-0.021	-0.040	-0.021	0.213	0.245	0.137	-0.089	-0.007	1.000						
snow	-0.125	-0.118	0.328	0.048	0.278	0.185	0.433	-0.116	-0.157	0.085	0.099	-0.264	-0.137	1.000					
stmdens	0.000	-0.014	0.065	-0.009	0.072	-0.081	-0.138	-0.014	-0.056	-0.020	-0.063	0.197	-0.052	-0.245	1.000				
dtriver	-0.295	0.157	0.283	0.163	0.150	0.220	0.513	0.156	0.266	0.191	0.252	-0.430	0.079	0.193	-0.429	1.000			
dtstream	0.002	0.100	-0.036	0.031	-0.001	0.038	0.135	0.128	0.183	0.046	0.045	-0.060	0.040	0.082	-0.314	0.229	1.000		
dtltdev	-0.346	0.164	0.479	0.784	0.148	0.418	0.446	0.164	0.182	0.792	0.126	-0.429	-0.088	-0.033	-0.088	0.261	0.088	1.000	
dthwy	-0.452	0.189	0.455	0.309	0.178	0.221	0.441	0.189	0.241	0.384	0.225	-0.840	-0.096	0.094	-0.221	0.412	0.184	0.433	1.000

Appendix D: Table 4. Correlation coefficients for sightings model.

	roadens	dthvydev	dtedge	dtdisturb	dtag	elev	vrm	dtwetland	dtroad	dtscrub	rdensit	dtwater	snow	stmdens	dtriver	dtstream	slope	dtltdev	dthwy
roadens	1.000																		
dthvydev	-0.642	1.000																	
dtedge	-0.169	0.093	1.000																
dtdisturb	-0.333	0.394	0.060	1.000															
dtag	-0.178	0.187	0.388	0.154	1.000														
elev	-0.454	0.498	0.066	0.298	0.187	1.000													
vrm	-0.273	0.284	-0.016	0.164	0.103	0.472	1.000												
dtwetland	-0.158	0.174	0.018	0.156	0.097	0.396	0.429	1.000											
dtroad	-0.478	0.322	0.344	0.138	0.216	0.233	0.162	0.054	1.000										
dtscrub	0.018	0.062	0.254	0.085	0.122	0.142	0.060	0.063	0.033	1.000									
rdensit	0.490	-0.563	-0.075	-0.265	-0.160	-0.237	-0.189	-0.116	-0.246	-0.016	1.000								
dtwater	-0.081	0.031	-0.071	0.013	-0.046	0.069	0.104	0.065	0.043	-0.156	0.030	1.000							
snow	0.111	-0.060	-0.062	-0.057	-0.058	-0.381	-0.183	-0.130	-0.055	-0.035	-0.010	-0.017	1.000						
stmdens	0.122	-0.137	-0.018	-0.080	-0.099	-0.170	-0.135	-0.203	-0.088	0.044	0.148	-0.010	-0.041	1.000					
dtriver	-0.281	0.300	0.012	0.166	0.079	0.293	0.208	0.203	0.165	0.007	-0.225	0.107	0.054	-0.496	1.000				
dtstream	-0.045	0.044	-0.020	0.029	0.015	0.137	0.177	0.276	0.019	-0.024	-0.052	0.046	0.001	-0.407	0.296	1.000			
slope	-0.274	0.286	-0.020	0.165	0.105	0.471	0.890	0.422	0.159	0.055	-0.189	0.114	-0.182	-0.133	0.209	0.166	1.000		
dtltdev	-0.366	0.174	0.379	0.084	0.178	0.176	0.464	0.162	0.725	0.079	0.126	0.476	-0.088	-0.033	-0.088	0.261	0.088	1.000	
dthwy	-0.452	0.189	0.455	0.309	0.178	0.221	0.185	0.189	0.241	0.384	-0.849	0.040	-0.960	0.094	-0.221	0.412	0.184	0.433	1.000

APPENDIX E

BOBCAT CAPTURE DATA

Appendix E: Table 1. Bobcat captures by cooperating trappers in southwestern New Hampshire during 2009-2010 field season. Ear tag number, sex, age, GPS collar brand, and capture locations (town, description, and coordinates) are indicated.

ID	Sex	Age	Collar type	Date	Town	Description	EASTING	NORTHING
26	M	4	Lotek	11/22/2009	Gilsum	Bears Den	723201	4767454
27	M	2	Lotek	1/13/2010	Westmoreland	London Rd	714579	4763559
28	F	10	Lotek	1/16/2010	Hancock	Middle Rd	256685	4760304
29	M	7	Sirtrack	1/19/2010	Antrim	Rt. 9, Hutchinson Residence	743205	4773625
30	M	5	Lotek	2/3/2010	Nelson	Apple Hill Rd	731213	4761568
31	M	9	Sirtrack	2/13/2010	Harrisville	Prospect St	737321	4759196
32	M	8	Sirtrack	2/13/2010	Harrisville	Hancock Rd	742465	4757868
33	M	5	Sirtrack	2/22/2010	Alstead	Rt. 123, Fuller Horse Farm	718104	4778590
34	M	3	Sirtrack	3/1/2010	Jaffrey	Gilmore Pond	739172	4742717
35	F	6	Sirtrack	3/6/2010	Jaffrey	Gilmore Pond	739182	4742715
39	M	3	Sirtrack	3/8/2010	Alstead	Rt. 123, Fuller Horse Farm	718102	4778592
40	M	5	Sirtrack	3/12/2010	Walpole	River Rd	709767	4778670

APPENDIX F

GPS COLLAR DATA

Appendix F: Table 1. Fix success and quality of locations obtained from GPS collars and their combination to comprise the dataset used for analysis. Lotek collars were set to a 5 hour fix schedule and Sirtrack collars were set to a 7 hour fix schedule. Data screening consisted of removing 2-dimensional GPS fixes with a dilution of precision (DOP) > 5.0.

Data Source	Expected Fixes	Fixes Obtained	Mean Fix Success	Fixes Post-Screening	Mean Data Retention (Post-Screening)	Mean Percent Data Usable vs. Expected
Lotek Collars	4280	3090	71.60%	2846	92.70%	66.20%
Sirtrack Collars	5470	2240	39.40%	1737	77%	30.51%
Full Dataset	9750	5330	54.70%	4583	86%	47%